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Anti-skywave AM broadcast antenna design

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NAVAL POSTGRADUATE SCHOOL
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THESIS

ANTI-SKYWAVE AM BROADCAST ANTENNA
DESIGN.

by

Sarfraz Hussain

March 1987

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This thesis investigates the design of an anti-skywave (ASW) AM broadcast antenna. The parameters of a typical AM broadcast antenna are presented first. Then the design proposed by Richard L. Biby is studied by numerical modeling with the Numerical Electromagnetic Code (NEC). Biby's proposed design involves a ring of short radiators with a conventional monopole operating over finite ground. To analyze the behaviour of Biby's proposed ASW antenna, a generic radiator study is conducted to test the ability of different sized radiators to launch the sky wave and the ground wave first as isolated elements and then as closely coupled radiators with cancelling phasing. Finally, some potential candidate structures are proposed for AM broadcast transmission which might achieve the desired characteristics of ground wave enhancement and sky wave suppression .

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ANTI-SKYWAVE AM BROADCAST ANTENNA DESIGN.

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requirements for the degree of

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ABSTRACT

This thesis investigates the design of an anti-skywave (ASW) AM broadcast antenna. The parameters of a typical AM broadcast antenna are presented first. Then the design proposed by Richard L. Biby is studied by numerical modeling with the Numerical Electromagnetic Code (NEC). Biby's proposed design involves a ring of short radiators with a conventional monopole operating over finite ground. To analyze the behaviour of Biby's proposed ASW antenna, a generic radiator study is conducted to test the ability of different sized radiators to launch the sky wave and the ground wave first as isolated elements and then as closely coupled radiators with cancelling phasing. Finally, some potential candidate structures are proposed for AM broadcast transmission which might achieve the desired characteristics of ground wave enhancement and sky wave suppression .

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I. INTRODUCTION

A. NEED FOR THE STUDY

In North America the medium frequency AM broadcast channels, depending on their coverage area, are described as clear, regional and local. In United States the AM broadcast stations are classified by Federal Communications Commission (FCC) as class I, II, III and IV for minimum required antenna performance and power limitations. Of these only the class I stations, operating on clear channels, are allowed to render ground wave service during day time and both ground wave and sky wave services at night. All other classes of AM broadcast stations are supposed to provide ground wave services only. However in practice the sky wave results in every class of AM broadcast transmissions, rather the bulk of the energy transmitted goes into the sky wave and considerably small portion constitutes the ground wave. This existance of the sky wave for class II, III and IV stations not only results in loss of efficiency, but can also cause severe undesired night time interference in regions where the station is not intended to be heard.

Therefore there is a need to design an antenna for the class II, III, and IV medium frequency AM broadcast stations which should cancel or suppress the sky wave and enhance the ground wave.

B. PROBLEM ENVIRONMENT

Most of the medium frequency AM broadcast stations use vertical radiators as antennas. The height of the radiator varies from one-sixth to five-eighths wavelength [Ref. 1: 25-2]. The economic considerations and the desired characteristics determine the height of the antenna for a particular AM broadcast station. Generally the height of the antenna is chosen to be one-quarter wavelength . The radiators can be either insulated at the base or grounded with shunt excitation. The current return path includes the space and the ground. Due to high current densities in the ground, the conductivity of the ground is raised by incorporating a radial buried ground system. The typical ground system consists of 120 quarter wave length long radial wires buried about 4 to 6 inches below the surface of the earth.

Figure 1.1 shows a typical AM broadcast antenna with a 120 quarter wave length long radial wire ground screen. The elevation radiation pattern of a typical AM

broadcast transmission is shown in Figure 1.2. The radiation pattern shows that the bulk of the energy goes into the sky wave. The electric field strengths at 1 KM for 1 KW input power and finite ground conductivity of 0.004 S/M are:

Ground wave : 272 mV/M

Sky wave : 210 mV/M

The input resistance is 37.3 ohms.

Besides improvements in the ground wave versus sky wave, the antenna system should also have reasonable impedance and bandwidth. The cost effectiveness of the designed antenna is also important. It should not make the existing antenna redundant, rather it should be able to use the existing quarter wave monopole and the 120 quarter wave long radial buried ground system and make the necessary modifications to affect the desired improvements. The new structure should also not demand expansion in terms of real estate as it might make it unfeasible for some radio stations.

C. STATEMENT OF THE PROBLEM

Efforts to increase the ground wave efficiency and reduce the sky wave interference of AM broadcast antennas have not been very successful in the past. Some structures like the ones designed by W.W.Hansen and Franklin do provide the desired results, but they have not been adopted for the reasons of either real estate or impractical size. Richard L. Biby has presented the design of an antenna [Ref. 2], which is claimed to meet the requirements of ground wave enhancement and sky wave suppression. Biby's concept is interesting as the design is shown to be suppressing the sky wave and enhancing the ground wave by approximately 6 dB. Biby has used his self generated Fortran code to analyze his design. Therefore the validity of the Biby's results need to be verified by modeling with some powerful and recognized computer modeling program like Numerical Electromagnetic Code (NEC).

Chapter II starts with the description of the Biby's proposed design. Then his proposed structure will be modeled using Numerical Electromagnetic Code (NEC). Based on the computer results the ground wave versus sky wave characteristics of this so called anti-skywave antenna will be analyzed. As Biby's design involves closely coupled short radiators, therefore it will be appropriate to do a generic radiator study which will help to explain the behaviour of the Biby's antenna.

Biby's proposed design employs only one ring consisting of 8 short "ring radiators". The idea seems to have stemmed from [Ref. 3], which proposes that

increased directivity in the vertical plane is possible by placing a set of short radiators either in a single ring or in multiple concentric rings driven with suitable phasing and amplitude ratio. Based on this concept some candidate ASW structures will be explored.

D. SCOPE AND LIMITATIONS

Though the medium frequency band spans from 300 to 3000 KHz, the broadcast service is restricted to a band from 535 to 1605 KHz [Ref. 1: 25-1]. In this thesis the research will be done at 1000 KHz as it is approximately in the middle of the limits of the AM broadcast band and Biby has also selected this frequency for his proposed antenna. If the research produces some solution model to the problem then it can be verified for the other frequencies in the band as well.

Numerical Electromagnetic Code [Ref. 4] will be used to model the radiating systems. As described in Appendix C, the computer simulation time increases with the number of segments in the model. How far the number of radials in the ground system can be reduced from 120 without affecting the performance seriously will be investigated.

Two special versions of NEC were used in this study. NPGNECI is a conventional NEC3 code with the added capability of allowing driving point currents to be specified and is limited to 300 wire segments. NECGSI also permits current drives but has highly efficient radial symmetry features, suited to monopoles with radial wire ground screens. The segment limit for NECGSI is 150 segments for the monopole and one symmetric radial section. Careful construction of the input data sets is necessary in order to stay within the segment limits of these codes.

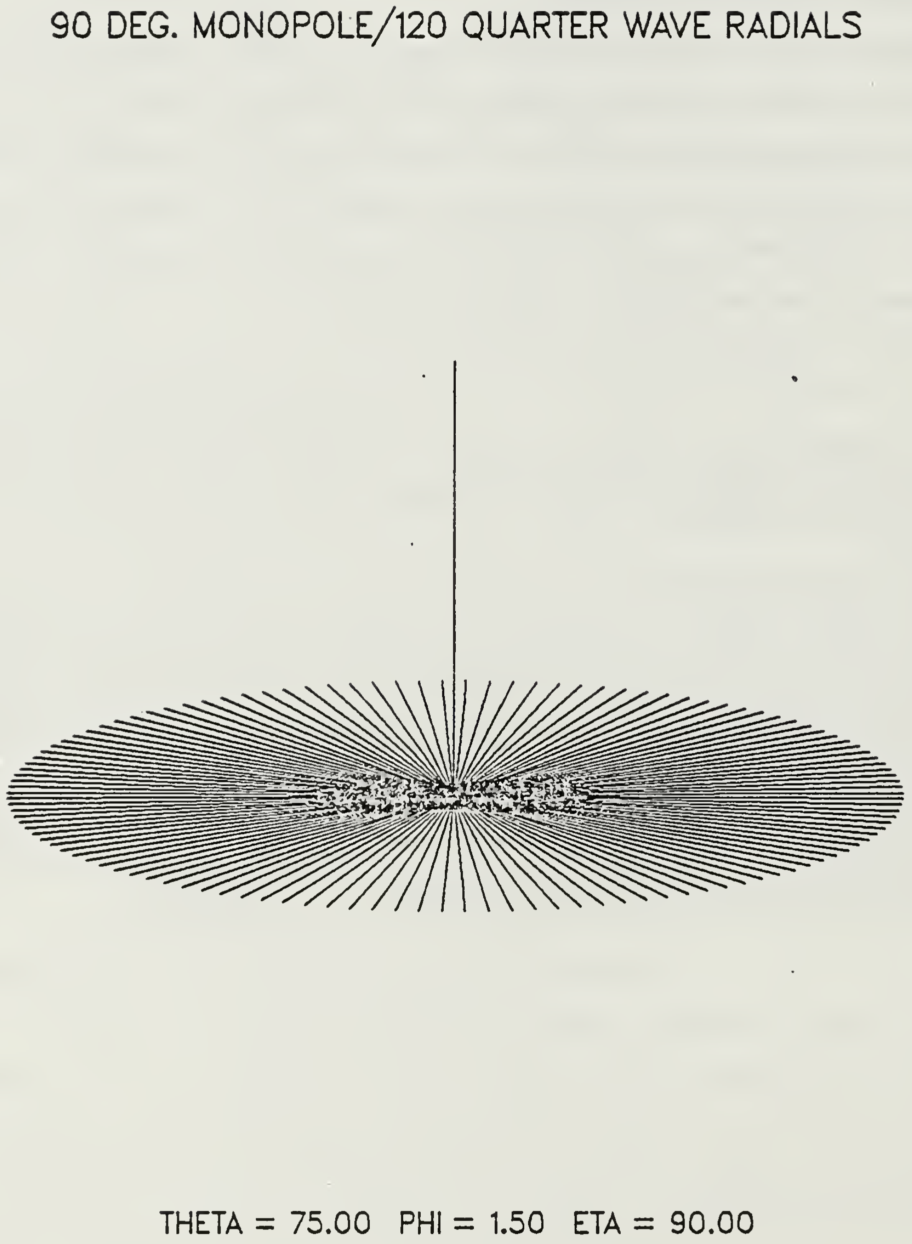


Figure 1.1 A Typical AM Broadcast Antenna - NEC Wire Model.

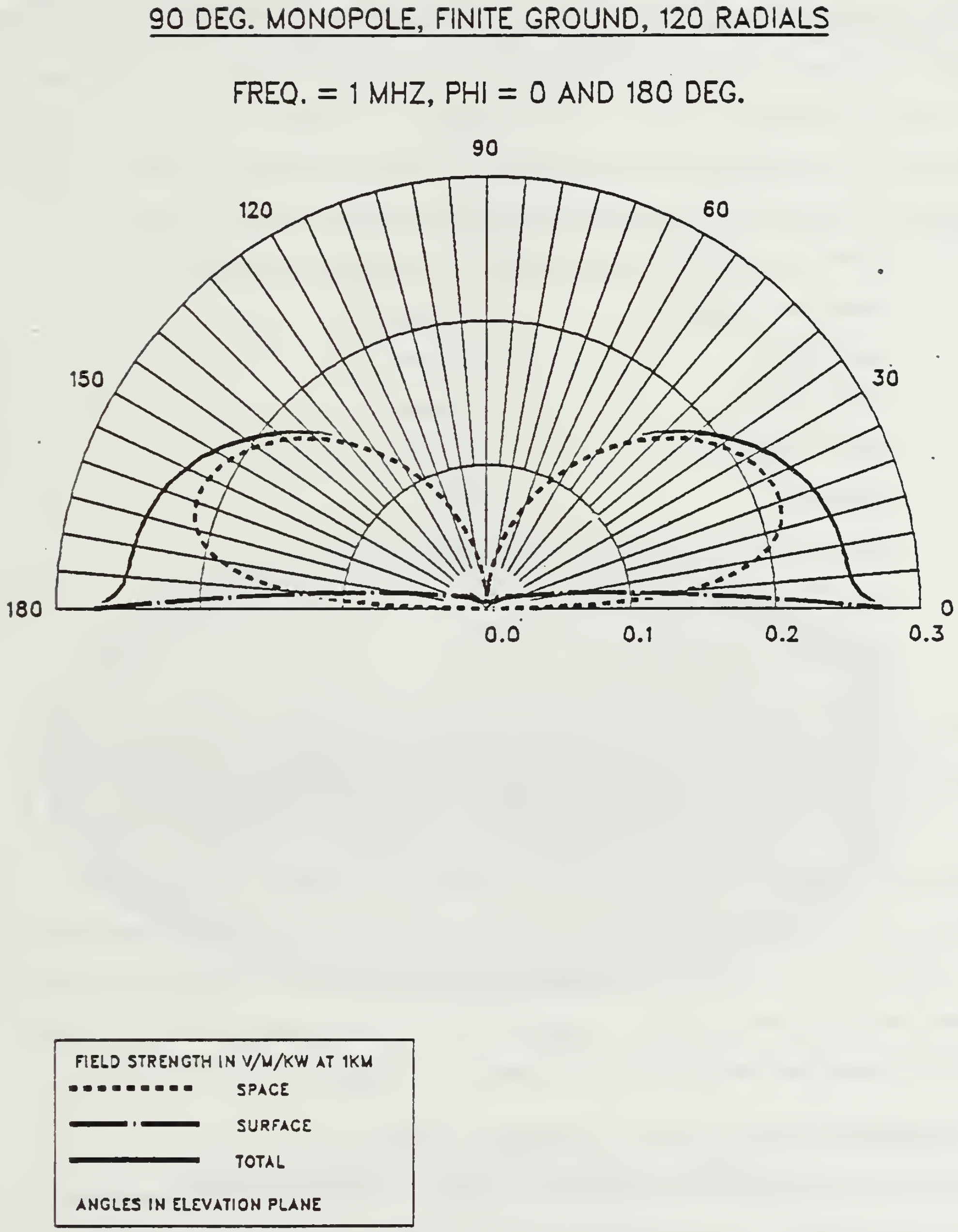


Figure 1.2 Vertical Radiation Pattern of an AM Broadcast Antenna over Finite Ground.

II. THE ANALYSIS OF BIBY'S ANTI-SKYWAVE ANTENNA

A. DESCRIPTION OF BIBY'S ANTI-SKYWAVE ANTENNA

Figure 2.1 and Figure 2.2 show the NEC wire models of Biby's proposed ASW antenna. It consists of a base fed quarter wave length long vertical monopole and eight 10 degrees high short ring radiators placed at a radial spacing of 5 degrees from the quarter wave monopole. The whole structure is simulated over a finite ground consisting of 120 quarter wave length long buried radial wire ground system. At the outer edges of the radial wires, a 10 degree high electrical fence is raised.

Biby modeled his ASW antenna with the following parameters:

monopole height	:	135 degrees
ring height	:	10 degrees
ring spacing	:	5 degrees
fence height	:	10 degrees
frequency	:	1MHz
earth conductivity	:	0.004 S/M
relative earth permitivity	:	15
monopole current drive	:	8.27 A
ring current drive	:	7.32 A

The resulting radiation pattern as obtained by Biby is shown in Figure 2.3. The unattenuated ground wave field strength is shown to have increased to 827.0 mV/M at 1 KM for 1 KW input power and the loop resistance dropped to 13.2 ohms. As mentioned in chapter I, the typical AM broadcast antenna has a ground wave field strength of 272 mV/M at 1 KM for 1 KW input power and a loop resistance of 37.3 ohms. It seems as if the Biby's antenna suffers slightly with regard to the drive point impedance, but has considerable enhancement of the ground wave. It is this claim which will be examined critically in the following sections.

B. COMPUTER MODELING OF BIBY'S ANTENNA

The Biby's ASW antenna with the parameters as described in section A of this chapter was modeled on the IBM 3033S computer at NPS main frame using the Numerical Electromagnetic Code (NEC). The listing of the data set used is given in Appendix B.1. The phase relationship between the drive currents for the monopole and

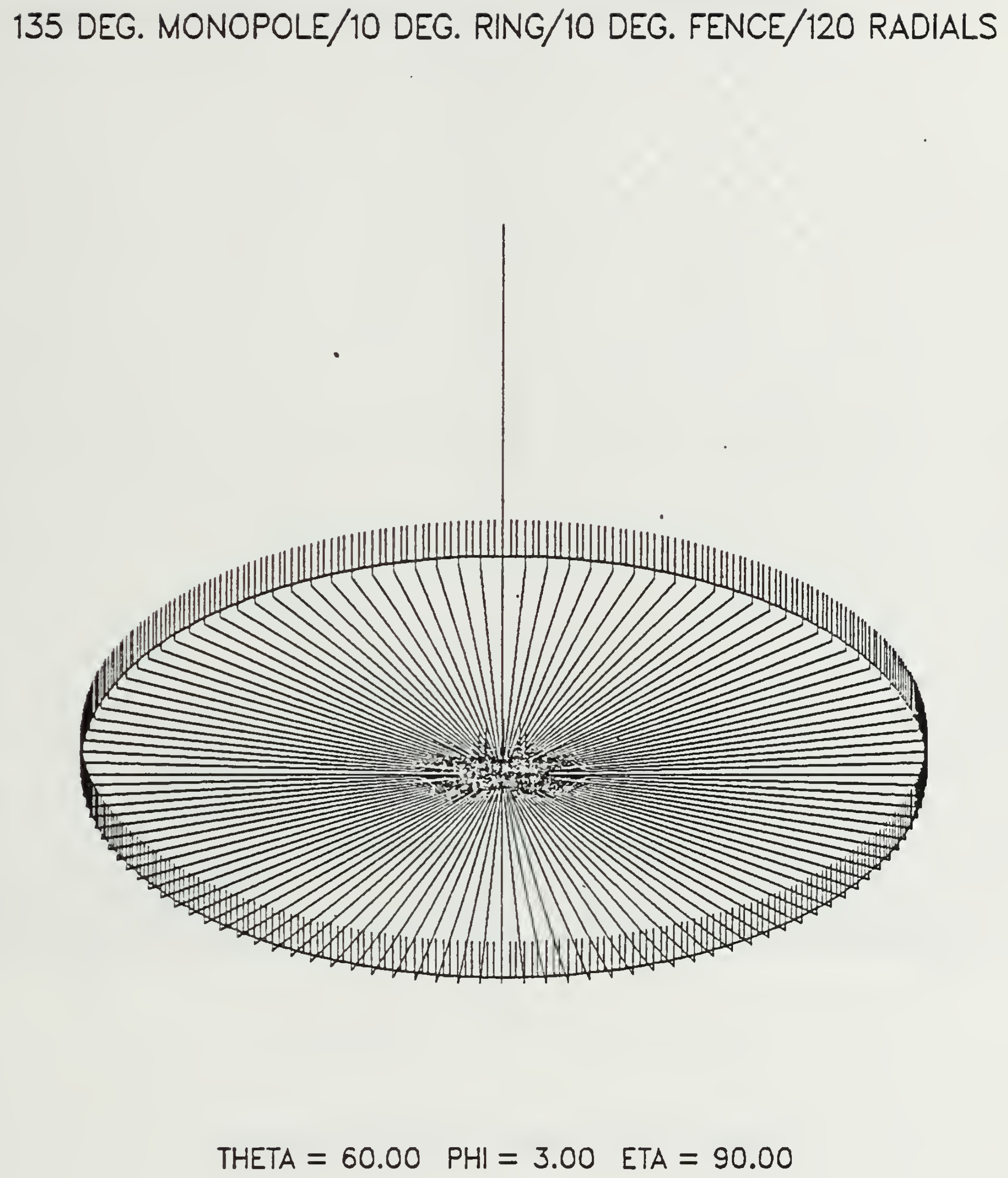


Figure 2.1 NEC Wire Model of Biby's ASW Antenna.

Figure 2.2 Biby's ASW Antenna - Driven Elements.

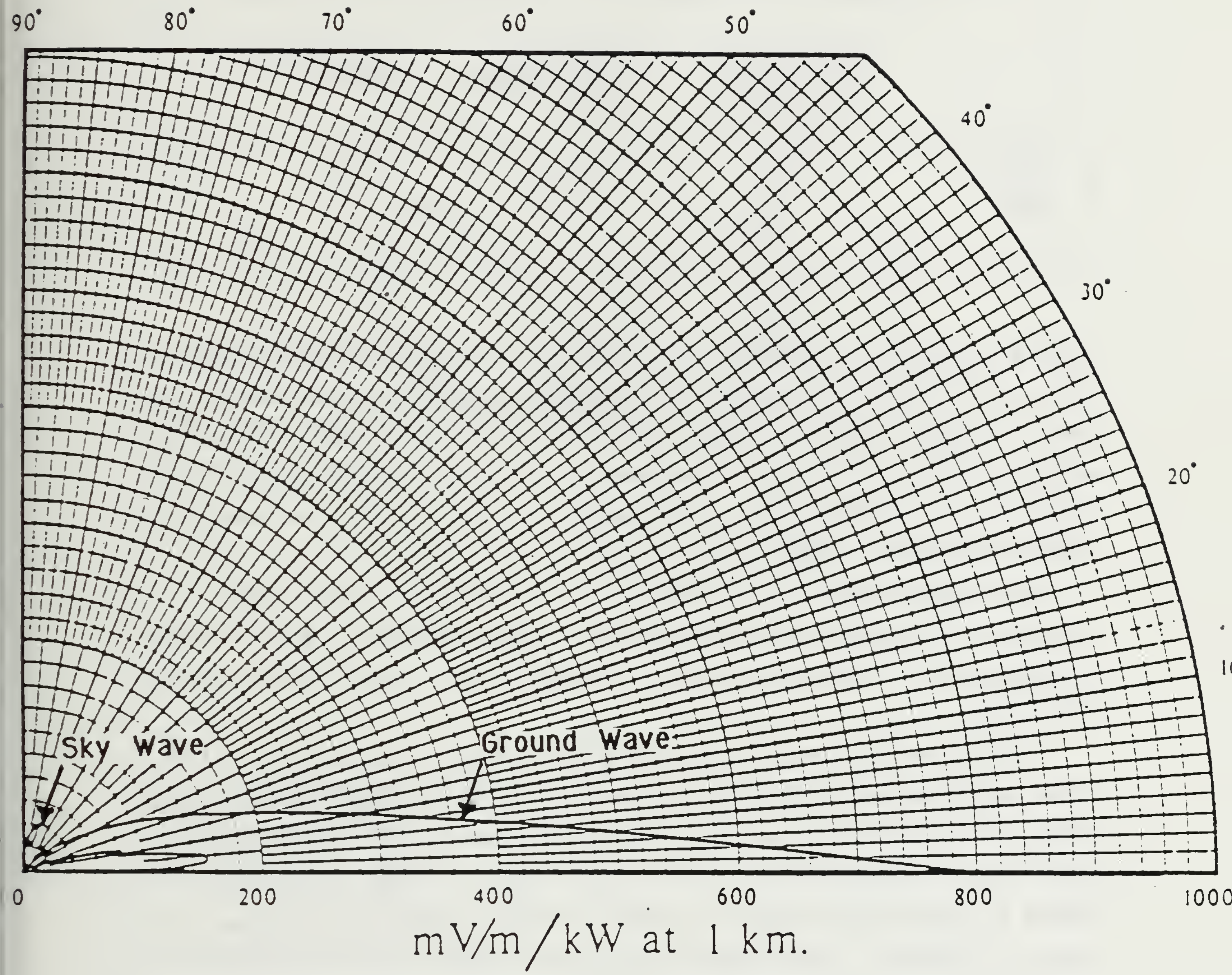


Figure 2.3 The Proposed Radiation Pattern of Biby's Antenna.

TABLE 1

COMPARISON OF BIBY'S RESULTS AND THE NEC RESULTS

	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Input Resistance in Ohms
Biby	827.0	45.0	13.2
NEC	33.1	45.1	127.23

the ring radiators is not specified in the paper written by Biby. A phase difference of 180 degrees between the monopole and ring drive currents will be assumed to model Biby's proposed antenna. Modeling Biby's current driven antenna with the fence exceeds the limit on the number of segments as imposed by NECGSI and NPGNECI. Therefore Biby's ASW antenna will be modeled using NEC without the fence and the effect of fence will be studied later in this chapter.

The radiation pattern as obtained by the NEC run is shown in Figure 2.4. A comparison of the results by Biby and the ones obtained via NEC is given in Table 1. As apparent from the table, the values obtained by NEC differ considerably from Biby's results.

Though the NEC model does not contain the fence as recommended by Biby, it would have made little difference. The fence is supposed to impede the out-of-phase ground wave generated by the short ring radiators without affecting the monopole's desired ground wave significantly. Later in this chapter the effect of the fence will be studied by reducing the number of radials to remain within the NEC limit on the number of segments. Since phasing of the current drives is also very important, the phase will also be varied on either side of 180 degrees to see if Biby's claims are valid. Biby suggests the use of a top hat to increase the effective length of the ring radiators, therefore the effect of top loading will also be studied.

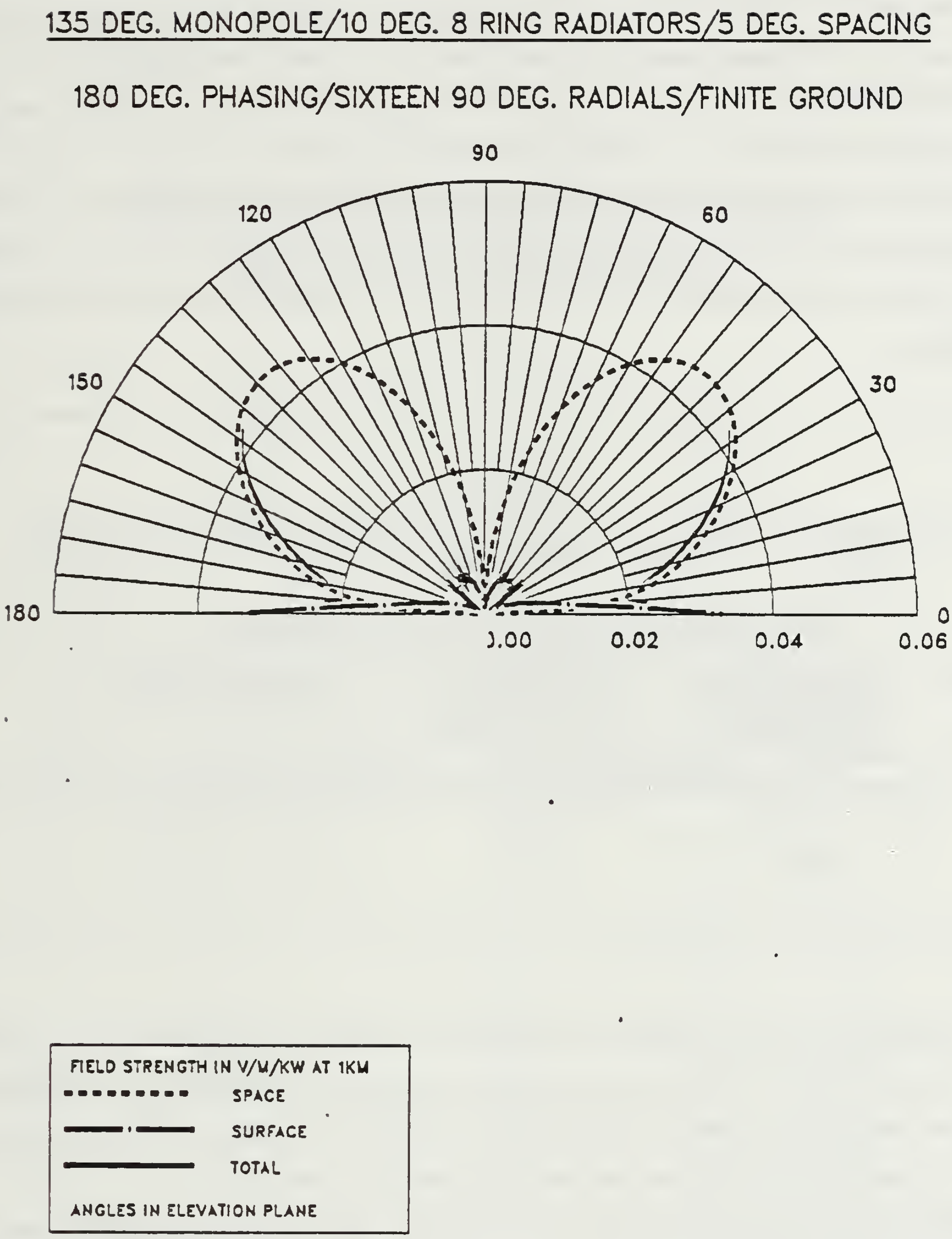


Figure 2.4 Radiation Pattern of Biby's Antenna - NEC Run.

1. Effect Of Reducing the Number Of Buried Radial Wires In the Ground System

The standard practice in the AM broadcast antenna is to have a buried ground system with 120 quarterwave radial wires. This raises the conductivity of the ground. NPGNECI and NECGSI are the two versions of NEC at NPS which support current sources. But they have a dimension limit as discussed in Chapter I. Therefore, it is appropriate to see the effect of reducing the number of radial wires from 120 down to 16 for the standard AM broadcast antenna. If the performance does not suffer drastically, then it will facilitate the study of fence and ring radiators with top hats for Biby's concept.

TABLE 2

COMPARISON OF RESULTS - VARYING THE NUMBER OF BURIED RADIAL GROUND WIRES

STANDARD AM BROADCAST ANTENNA

Number of Radial Wires	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Input Resistance in Ohms
120	273.9	216.2	38.916 + j22.289
16	260.3	204.9	44.544 + j26.166

The data sets used to model a typical AM broadcast antenna with 120 radial wires and the one with 16 radial wires are given in Appendix B.2 and B.3 respectively. The elevation radiation patterns as produced by NEC are shown in Figure 2.5 and Figure 2.6. A comparison of the output results is given in Table 2.

Reducing the number of radial wires reduces the ground wave field strength from 273.9 mV/M to 260.3 mV/M, but it also decreases the sky wave proportionally. Due to decreased conductivity, the drive point impedance increases with 16 radial wires. These results allow further study of Biby's concept with a 16 buried radial wire ground system.

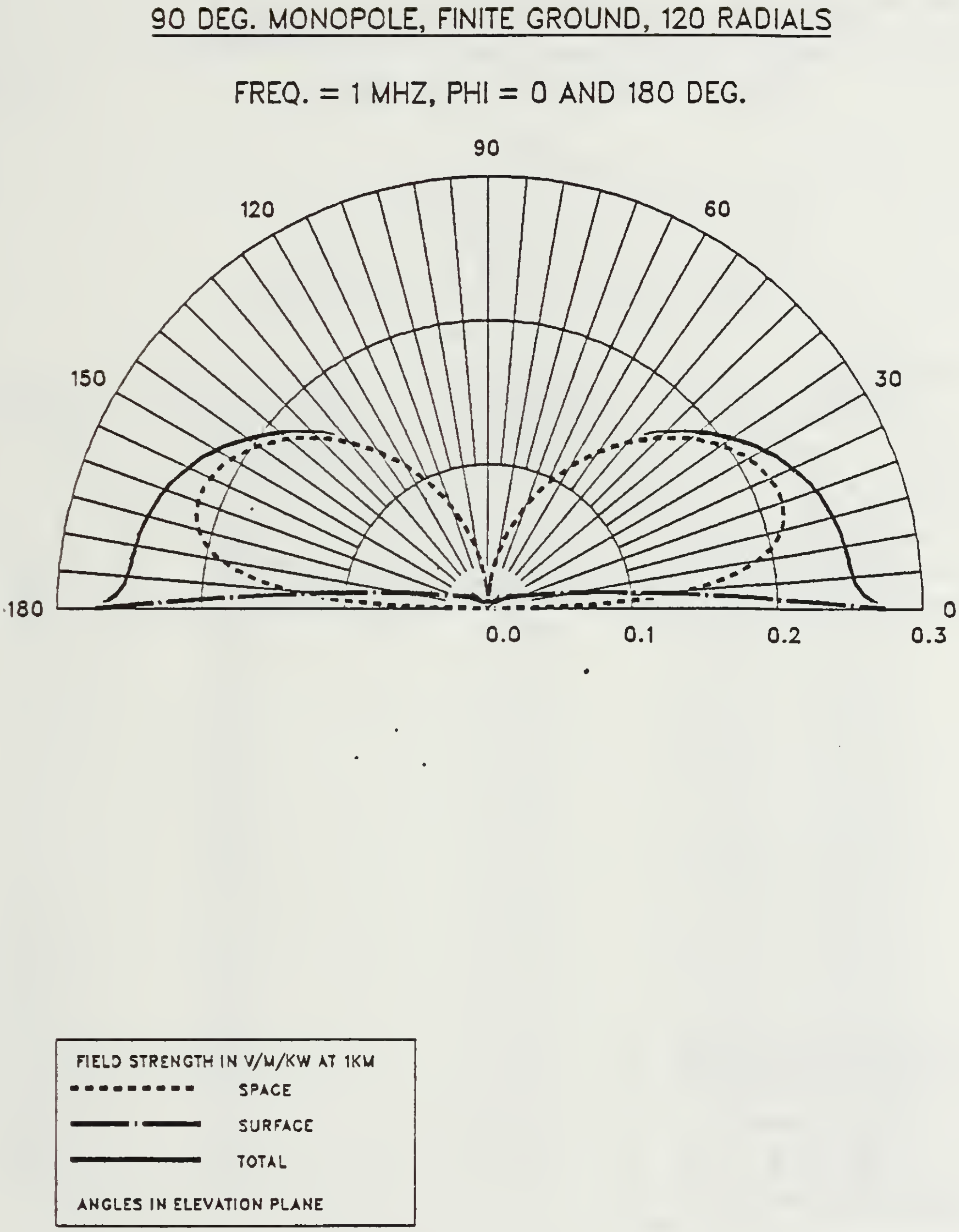


Figure 2.5 Elevation Radiation Pattern - 120 Radial Wire Ground Screen.

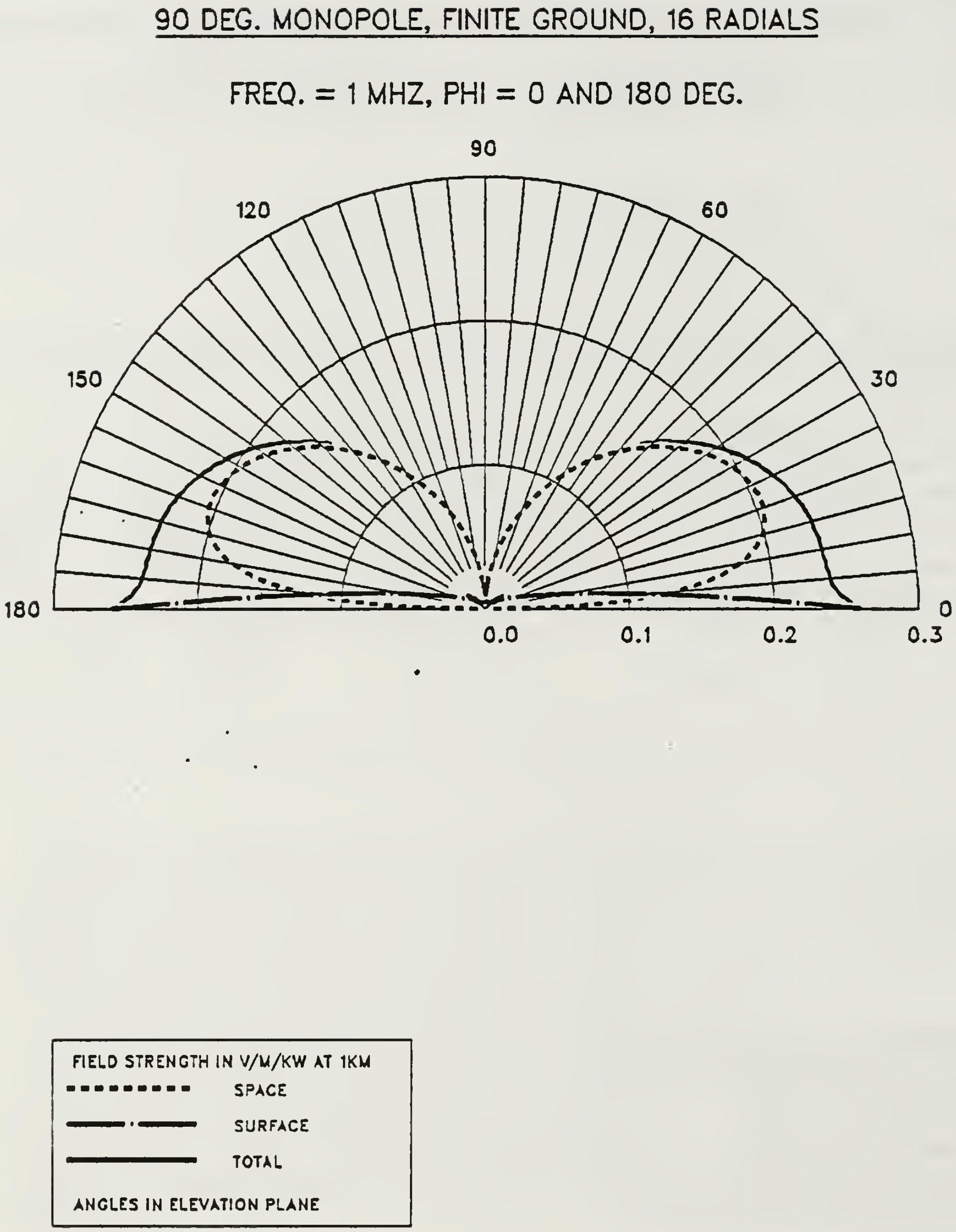


Figure 2.6 Elevation Radiation Pattern - 16 Radial Wire Ground screen.

2. Effect of Varying the Phase

In the begining of this section, Biby's ASW antenna was modeled using NEC with a phase difference of 180 degrees between the drive currents. The results were not close to the ones claimed by Biby. The cancellation of the monopole's sky wave by the ring's sky wave did not take place, but hopefully it might for phase in the vicinity of 180 degrees. In an effort to find this cancelling phase, the ASW antenna will be modeled using NEC with the drive currents phase difference scanned on either side of 180 degrees.

TABLE 3

EFFECT OF VARYING THE PHASE

Phase Difference in Degrees	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Input Impedance (r + jx) Ohms
170.0	60.0	52.8	6.346 + j53.822
170.5	58.6	51.5	6.107 + j53.486
171.0	57.3	50.1	5.869 + j53.148
171.5	56.0	48.8	5.634 + j52.808
172.0	54.7	47.5	5.406 + j52.468
172.5	53.5	46.2	5.178 + j52.124
173.0	52.3	44.9	4.952 + j51.778
173.5	51.2	43.6	4.730 + j51.431
174.0	50.1	42.4	4.511 + j51.082
174.5	49.1	41.2	4.295 + j50.731
175.0	48.2	40.1	4.084 + j50.378
175.5	47.4	39.0	3.874 + j50.022
176.0	46.7	38.0	3.669 + j49.666
176.5	46.0	37.0	3.462 + j49.307
177.0	45.6	36.1	3.265 + j48.947
177.5	45.3	35.4	3.065 + j48.584
178.0	45.2	34.7	2.872 + j48.221
178.5	45.2	34.2	2.684 + j47.856
179.0	45.5	33.2	2.494 + j47.489
179.5	45.9	33.6	2.310 + j47.121
180.0	46.5	33.6	2.129 + j46.750
183.0	54.9	37.2	1.109 + j44.496
183.4	56.6	38.2	0.982 + j44.191
183.5	49.6	34.8	1.759 + j45.787
183.6	57.5	38.7	0.920 + j44.039
183.9	58.9	39.6	0.829 + j43.810
184.3	60.9	40.8	0.707 + j43.504
184.4	61.4	41.1	0.677 + j43.427
184.5	61.9	41.5	0.677 + j43.427

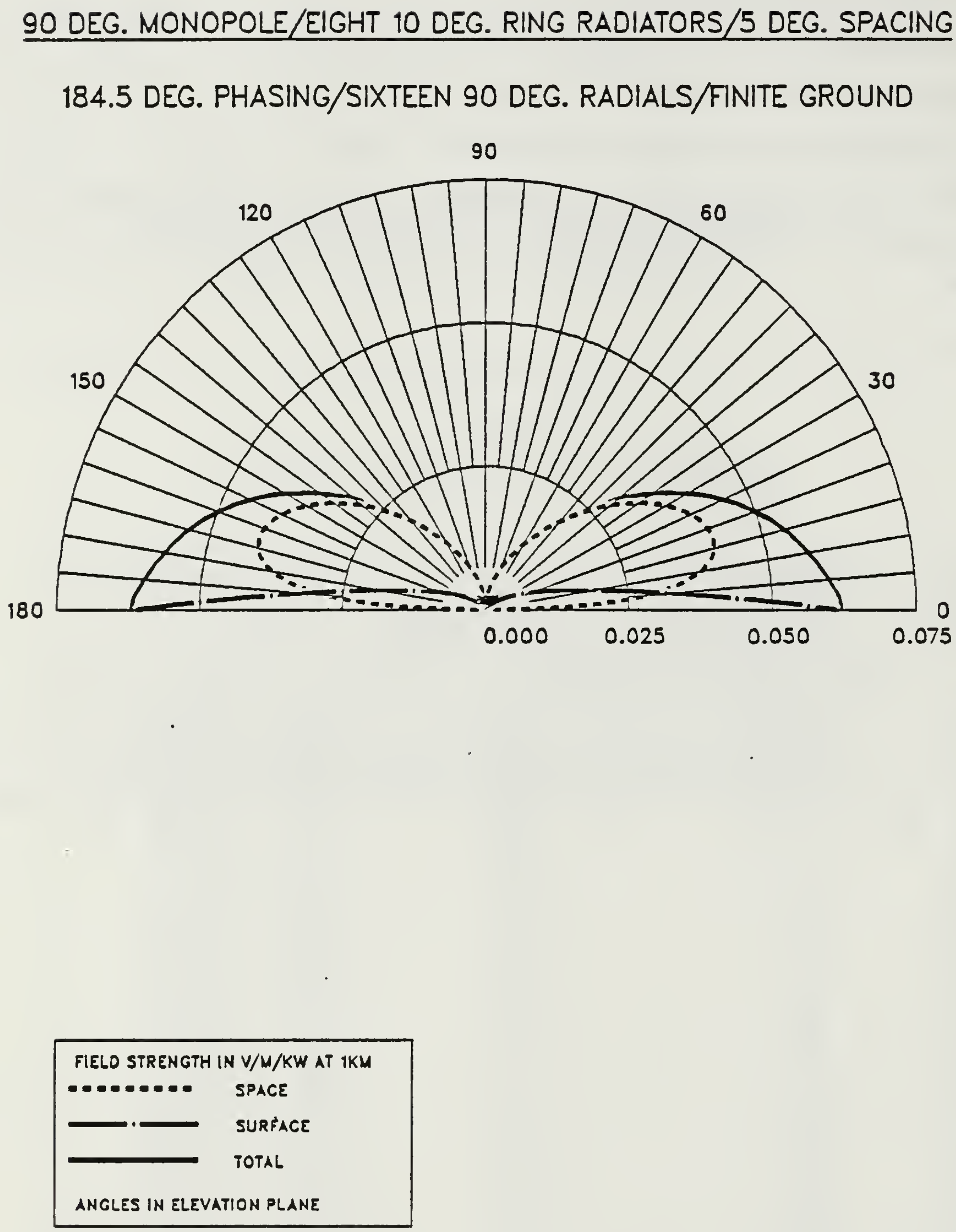


Figure 2.7 Radiation Pattern - Phase Difference = 184.5 Degrees.

The ASW antenna with the following parameters was used for this study:

ring height	:	10 degrees
frequency	:	1 MHz
earth conductivity	:	0.004 S/M
relative earth permitivity	:	15

The results of different NEC runs are given in Table 3. As the phase is reduced from 180 degrees, the ground wave field strength starts increasing relative to the value at 180 degrees, but so does the sky wave. The drive point impedance also increases as the phase is reduced. Similar effects are observed when the phase difference is increased from 180 degrees, except that the drive point impedance now decreases as the phase difference is increased. Due to this reduction of drive point impedance, the phase difference was not varied beyond 184.5 degrees. The listing of the data set used for the NEC run with the drive current phase difference of 184.5 degrees is given in Appendix B.4.

All these variations are not significant as there is an overall attenuation of the radiated energy. The lossy ground seems to be soaking up most of the power. The highest value of the ground wave field strength achieved is 60.9 mV/M as shown in Figure 2.7, which is 12.9 dB down from the one produced by the typical AM broadcast antenna. The null in the radiation pattern is also not steerable.

3. Effect of Top Loading the Ring Radiators

Biby suggests the use of quarter wave length long top hats for the short ring radiators to increase their effective length [Ref. 2: p-11,13]. The ASW antenna with a drive current phase difference of 184.5 degrees was used to study the effect of different top hats. The data set used for a typical NEC run with top hat length of $\lambda/4$ is given in Appendix B.5. The results of the NEC runs are given in Table 4. The radiation patterns of the ASW antenna with different top hats are shown in Figures 2.9 to 2.11. For comparison the radiation pattern of the same structure without the top hat is shown in Figure 2.8. The top load does not seem to aid in enhancing the ground wave and in canceling the sky wave significantly. However, the shape of the radiation pattern does change with a top hat. With a $\lambda/32$ top hat, the suppression of the sky wave is relatively higher than the suppression obtained by the structure with no top hat. As the length of the top hat is increased to $\lambda/16$, the ground wave increases slightly but so does the sky wave. By increasing the top hat to $\lambda/4$, the length

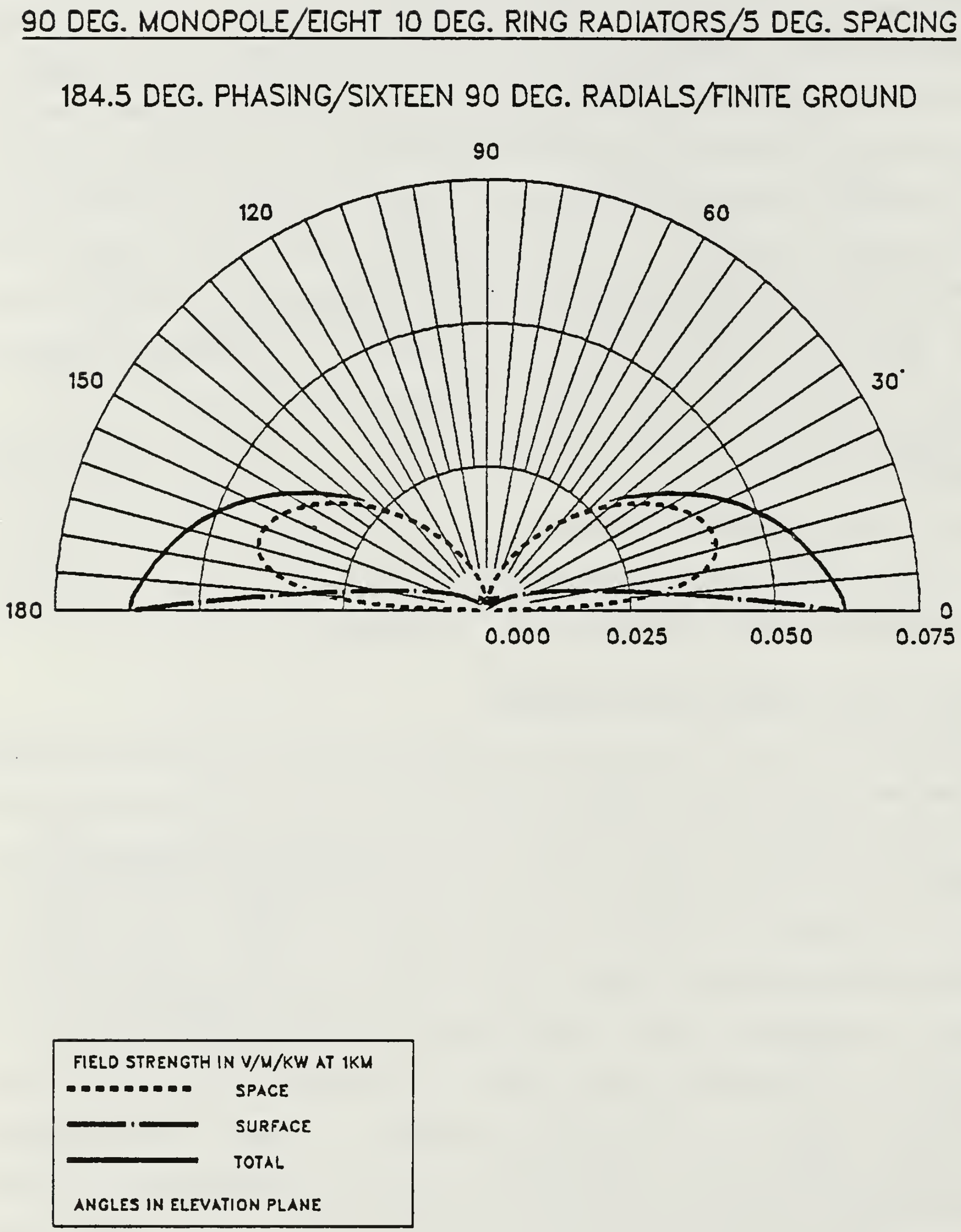


Figure 2.8 Radiation Pattern - No Top Hat.

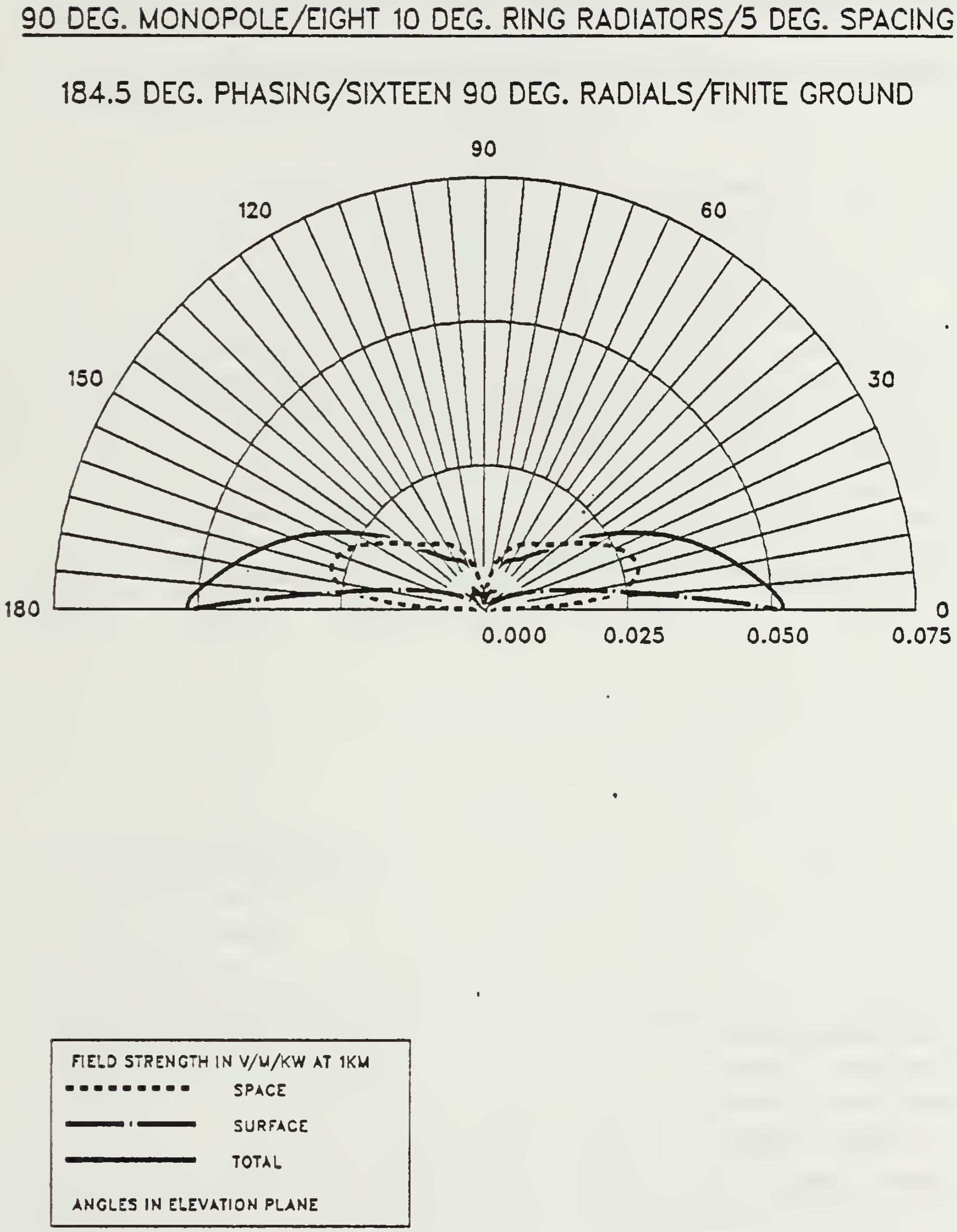


Figure 2.9 Radiation Pattern - $\lambda/32$ Top Hat.

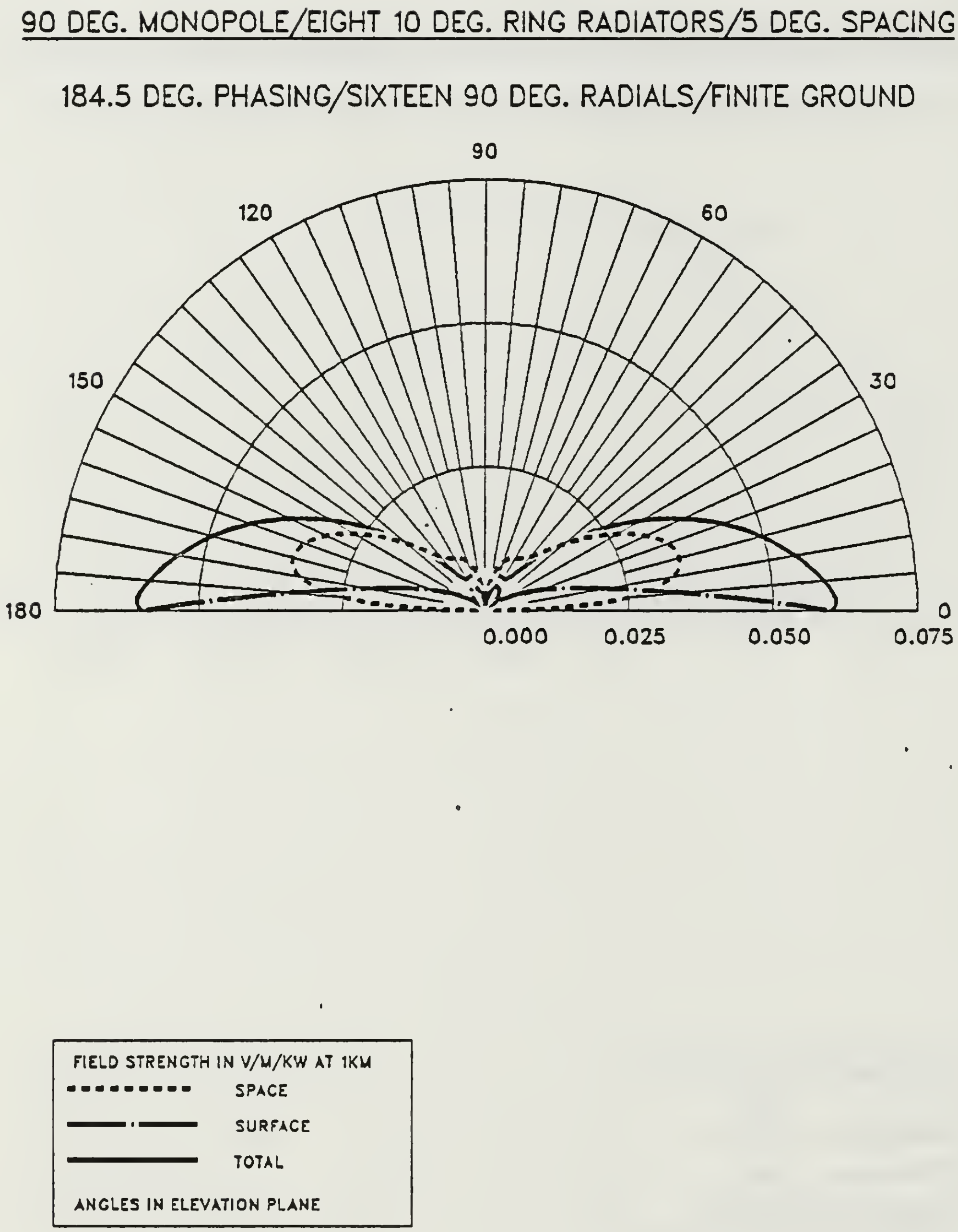


Figure 2.10 Radiation Pattern - $\lambda/16$ Top Hat.

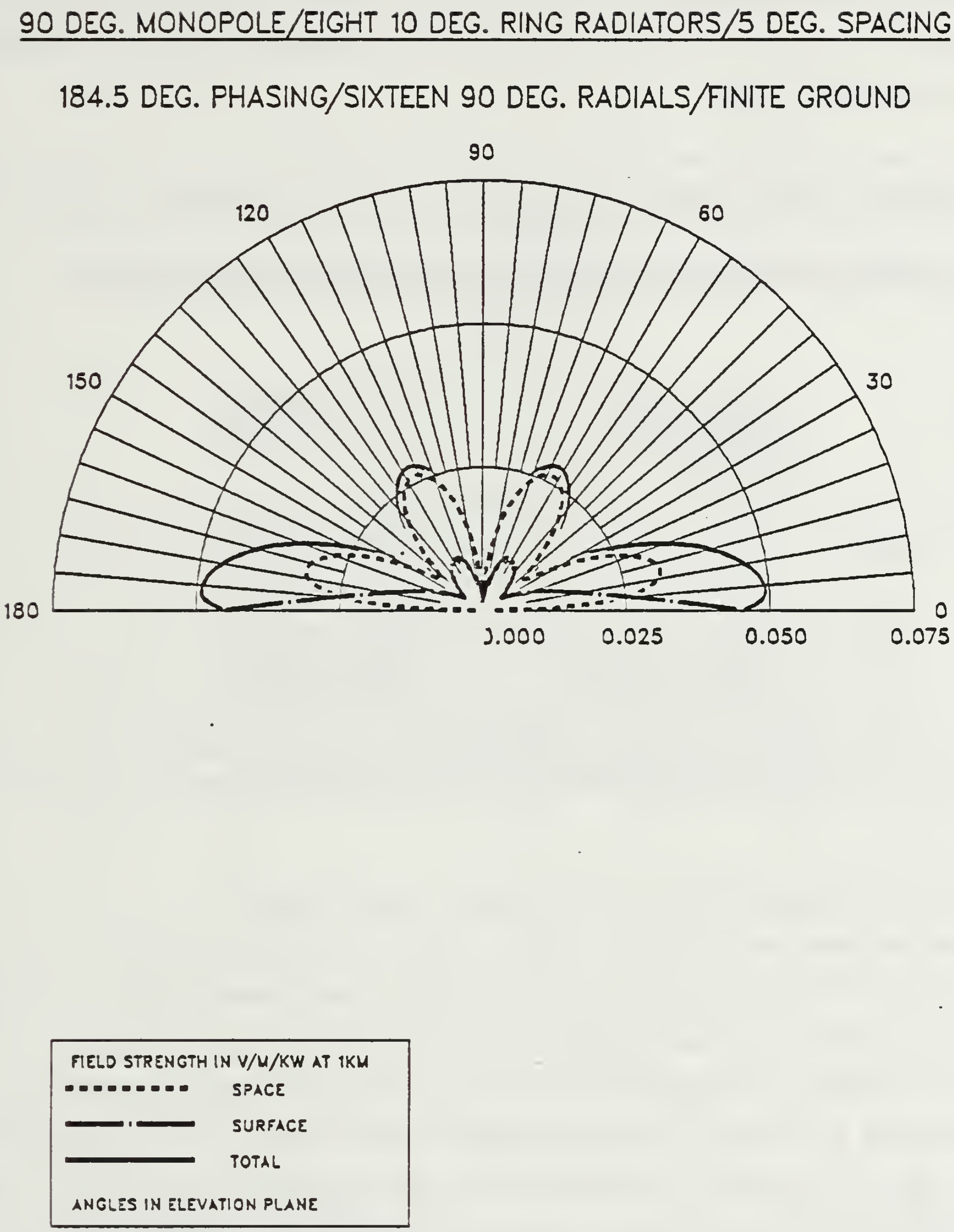


Figure 2.11 Radiation Pattern - λ/4 Top Hat.

suggested by Biby, not only does the ground wave field strength decrease, but the antenna starts generating multiple sky wave lobes in the radiation pattern. The increase in the number of sky wave lobes can add to the problem by causing undesired interference at multiple ranges.

TABLE 4

EFFECT OF VARYING THE TOP HAT OF THE SHORT RING RADIATORS

Length of The Top Hat	Ground Wave Field Strength in mV/M/KW at 1KM	Input Impedance (r + jx) Ohms
No Top Hat	61.9	5.634 + j52.808
$\lambda/32$	52.0	6.346 + j53.822
$\lambda/16$	61.0	6.107 + j53.486
$\lambda/4$	49.2	5.869 + j53.148

4. Effect of Varying the Phase For the 90 Deg. Long Top Hat

In the preceding section Biby's ASW antenna was studied for different top hat lengths. The $\lambda/4$ i.e 90 degree long top hat with drive current phase difference of 184.5 degrees did not show any improvement in the ground wave versus sky wave characteristics. As Biby has suggested the use of $\lambda/4$ top hat for the ring radiators, the ASW antenna with a $\lambda/4$ top hat will be modeled with different drive current phase difference to see if it enhances the ground wave and suppresses the sky wave. The results of different NEC runs are given in Table 5. The radiation patterns obtained are shown in Figure 2.12 to Figure 2.15.

As shown in Figure 2.13 and Figure 2.15, the multiple lobes in the radiation patterns remain when the drive current phase difference is varied half a degree from 184.5 degrees. At the phase difference of 180.0 degrees, which not only eliminates the extra lobes being produced in the radiation pattern, but also gives a ground wave field strength of 113.3 mV/M, the best value is obtained so far in this study of the ASW

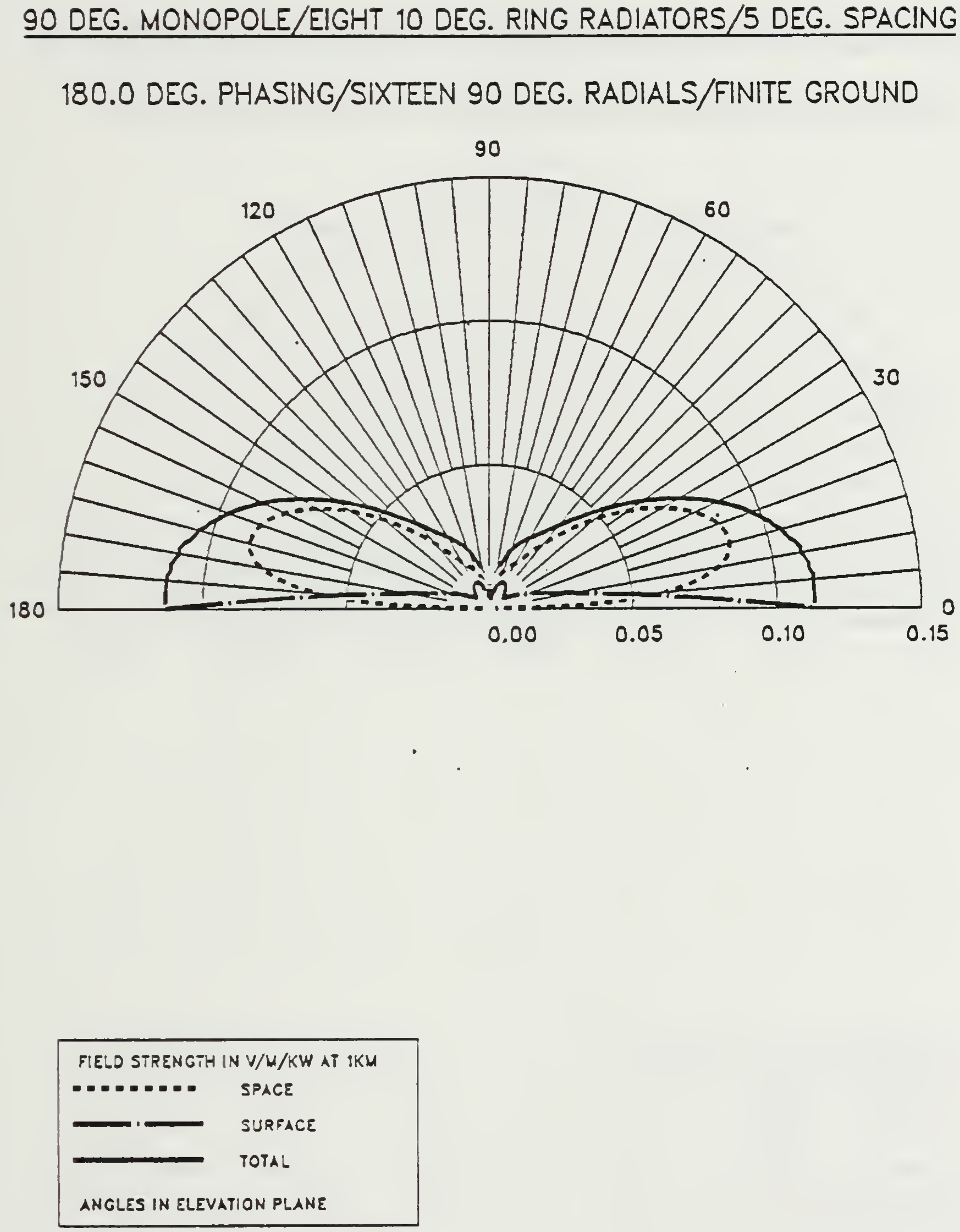


Figure 2.12 Radiation Pattern - $\lambda/4$ Top Hat, $\Delta\Phi$ = 180.0 Degrees.

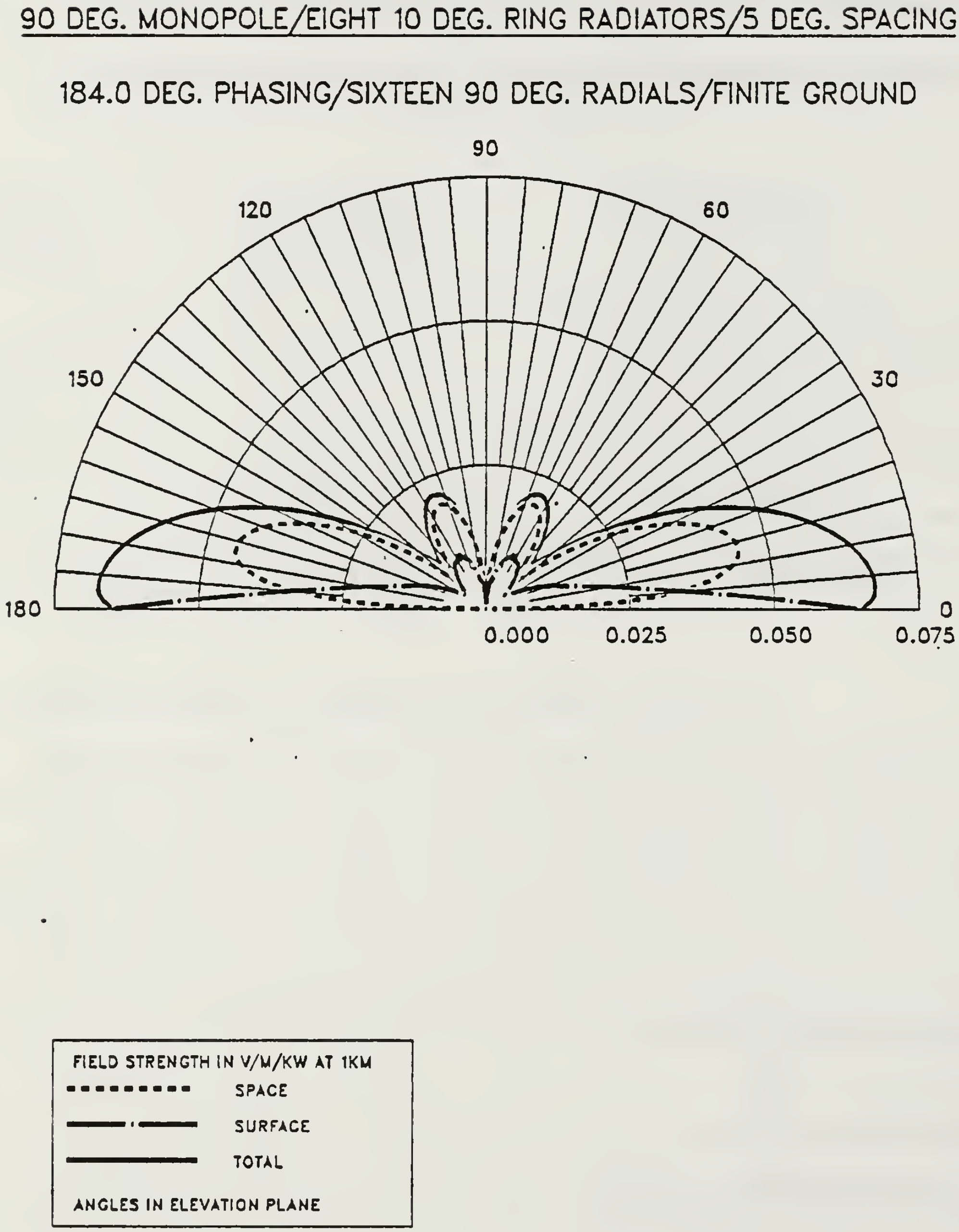


Figure 2.13 Radiation Pattern - $\lambda/4$ Top Hat, $\Delta\Phi$ = 184.0 Degrees.

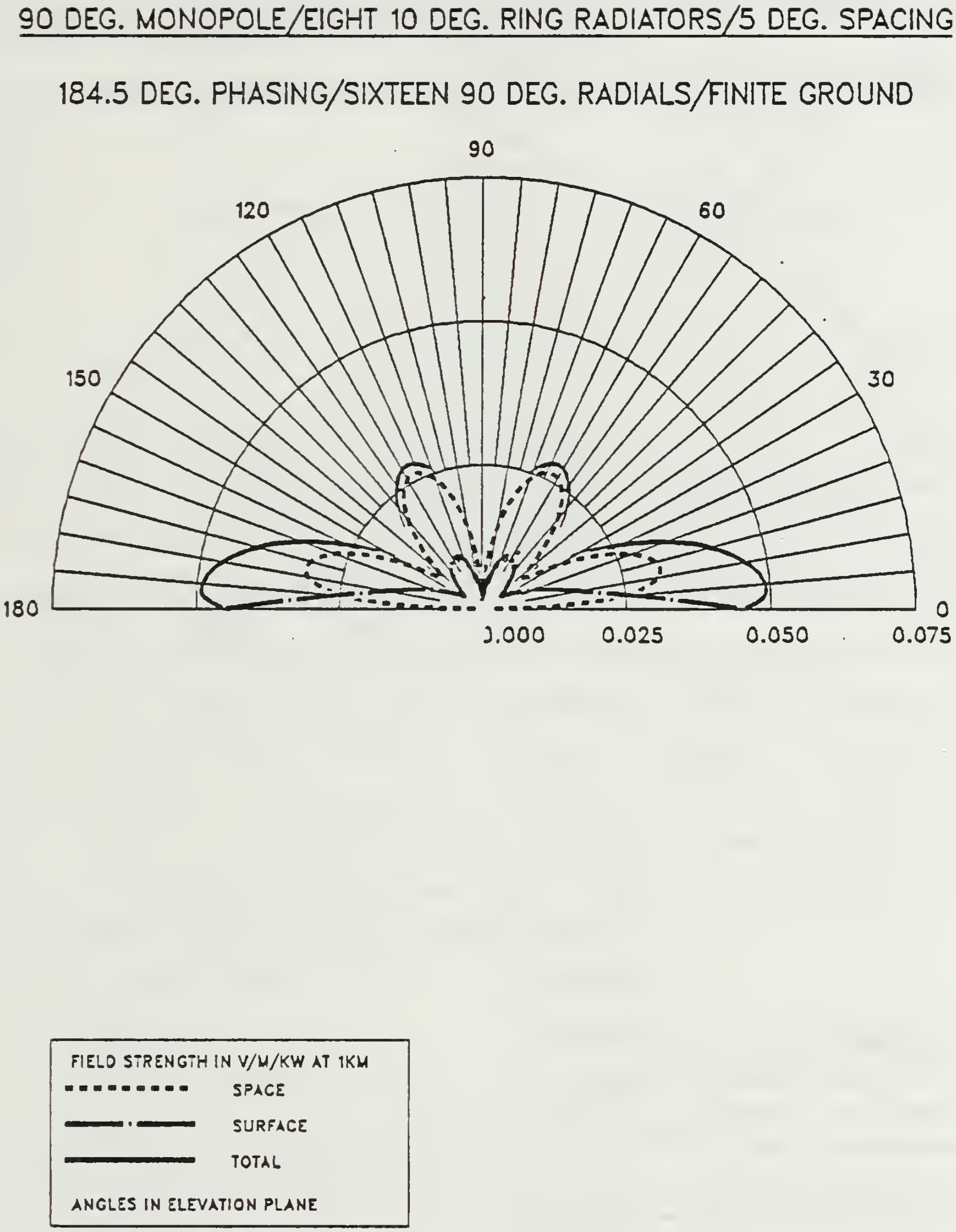


Figure 2.14 Radiation Pattern - $\lambda/4$ Top Hat, $\Delta\Phi$ = 184.5 Degrees.

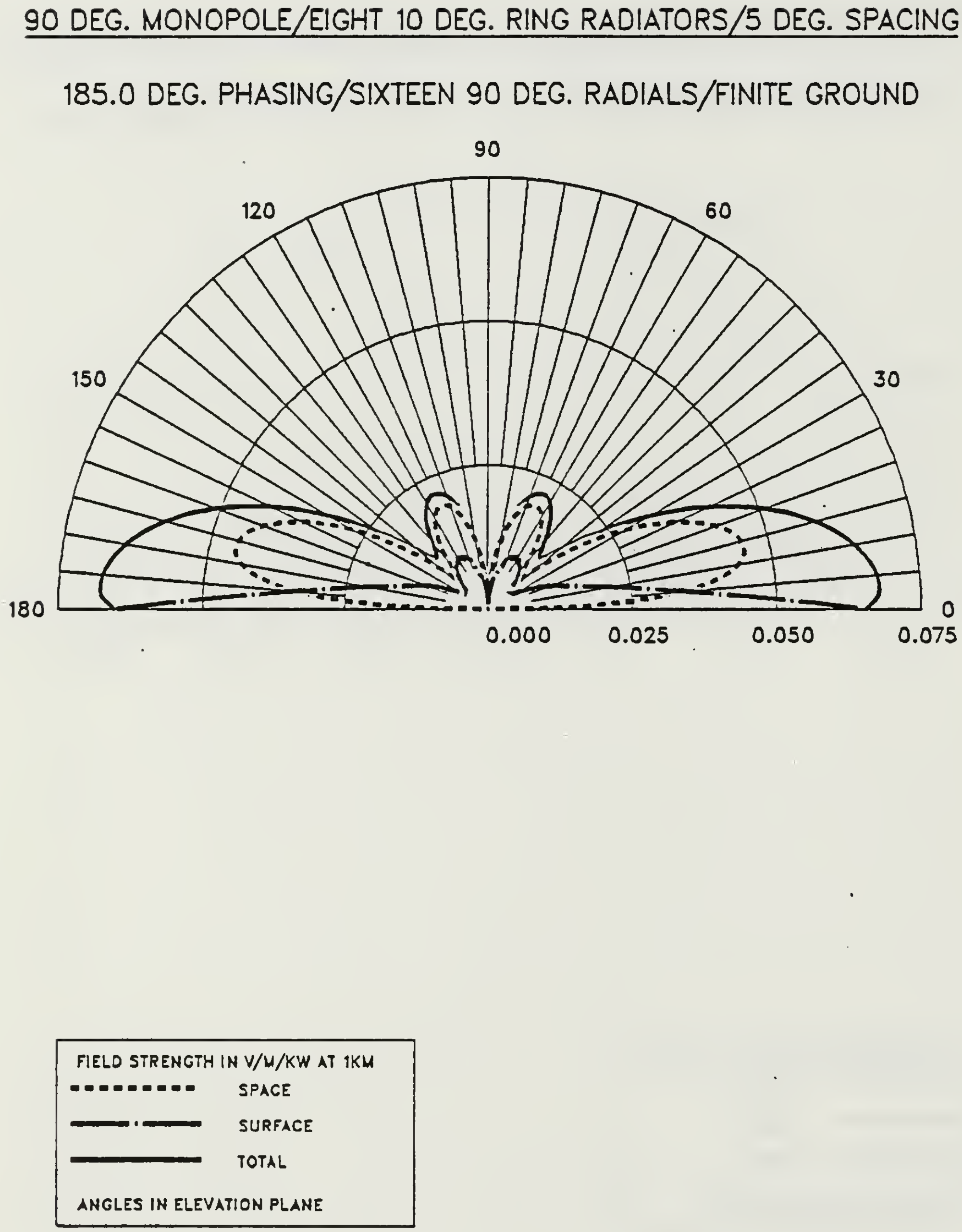


Figure 2.15 Radiation Pattern - $\lambda/4$ Top Hat, $\Delta\Phi$ = 185.0 Degrees.

TABLE 5

EFFECT OF VARYING THE PHASE - 90 DEG. LONG TOP HAT

Phase Difference in Degrees	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Input Impedance (r + jx) Ohms
180.0	113.3	86.7	1.431 - j69.907
184.0	67.5	19.8	5.373 - j89.677
184.5	49.2	26.3	0.934 - j96.748
185.0	67.8	19.7	4.784 - j89.222

antenna. However, compared with the typical value of 272.0 mV/M produced by the standard AM broadcast antenna, the proposed ASW antenna is still low in ground wave performance.

5. **Effect of Varying the Fence Height**

The vertical fence placed at quarter wave from the origin forms an important element of Biby's proposed design. Biby has suggested a height of 10 degrees for the fence [Ref. 2]. Due to the short height of the fence, it is assumed to be attenuating the out-of-phase ground wave produced by the short ring radiators without affecting appreciably the ground wave generated by the taller quarter wave high monopole. The effects of a 10 degree high fence and increasing its height will be studied by modeling the proposed ASW antenna with the following parameters:

monopole height	:	90 degrees
ring height	:	10 degrees
ring top hat length	:	80 degrees
fence height	:	10, 20, 30 degrees
no. of buried radials	:	16
frequency	:	1MHz
earth conductivity	:	0.004 S/M
relative earth permitivity	:	15
drive current phase difference	:	180 degrees

Modeling the fence requires a large number of segments. The reduction in the number of buried radial wires from 120 to 16 allows us to remain within the limit of 150 segments as imposed by NECGSI and the 300 by NPGNECI. Biby has suggested a length of quarter wave for the top hat, which is not practical as the ring radiators are already spaced 5 degrees from the origin and the top hat also has to be isolated from the fence. A spacing of 5 degrees is assumed between the top hat and the fence, which allows a maximum length of 80 degrees for the top hat. The listing of the data set used for a typical NEC run for this study is given in Appendix B.6. The radiation patterns obtained are shown in Figures 2.16 to 2.18.

TABLE 6

EFFECT OF VARYING THE FENCE HEIGHT

Fence Height in Degrees	Ground Wave Field Strength in mV/M/KW at 1KM	Space Wave Field Strength in mV/M/KW at 1KM	Input Impedance (r + jx) Ohms
No Fence	113.3	86.7	1.431 - j69.907
10	133.0	101.3	4.906 - j60.575
20	134.5	102.2	4.759 - j61.779
30	137.7	103.7	4.816 - j62.375

The 10 degree high fence is not attenuating the ring ground wave as expected (Table 6), rather its inclusion adds to sky wave. As the height of the fence is increased to 20 and 30 degrees both the ground wave and the sky wave field strengths increase by a small amount. This small increase in the field strength is assumed to be taking place due to the reradiation of the energy from the fence. These results show that the fence at quarter wave from the origin is not accomplishing the purpose of attenuating the ring ground wave without affecting the monopole ground wave appreciably. This result is consistent with a fence study reported by R. W. Adler, earlier [Ref. 5].

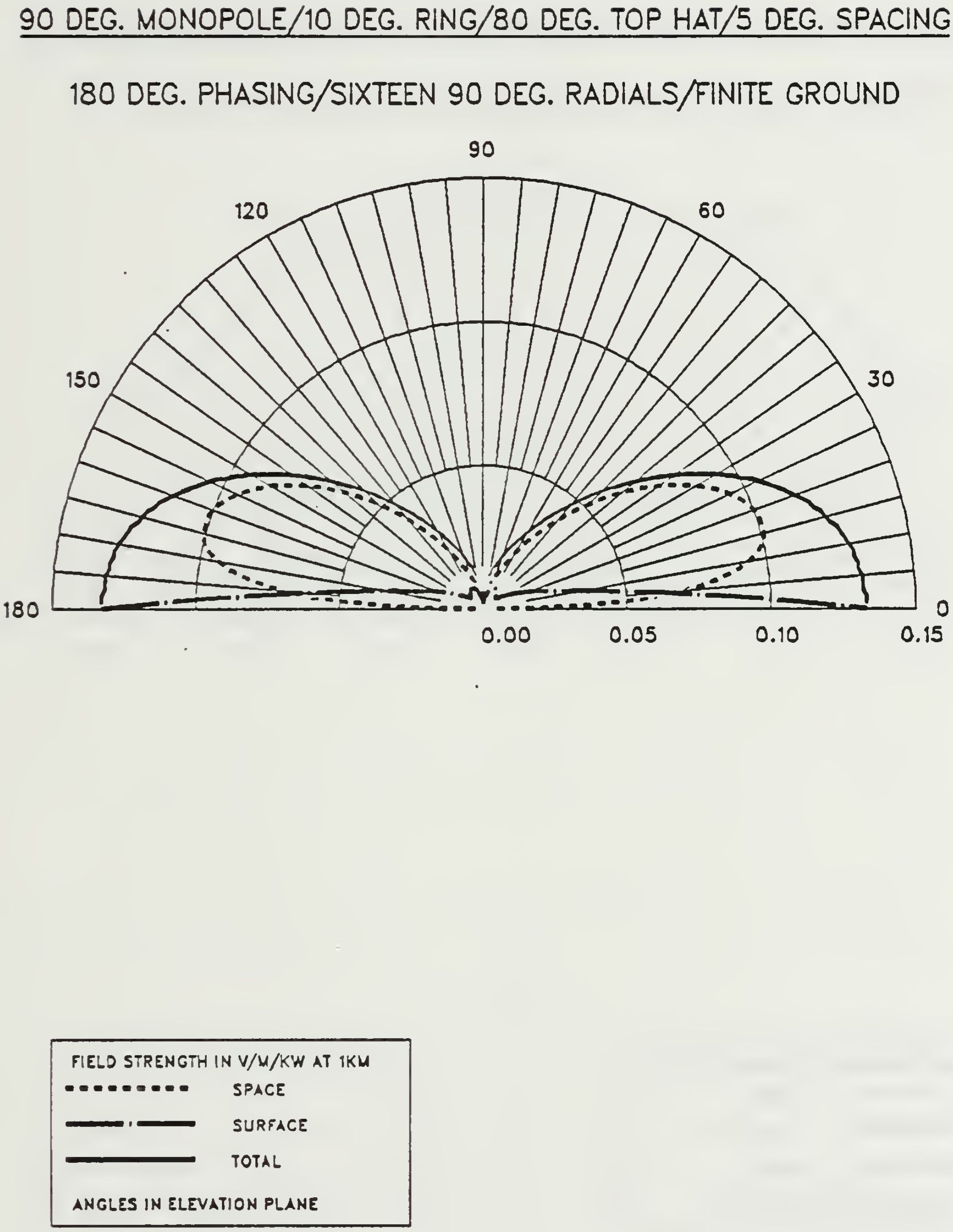


Figure 2.16 Radiation Pattern - 10 Deg. High Fence.

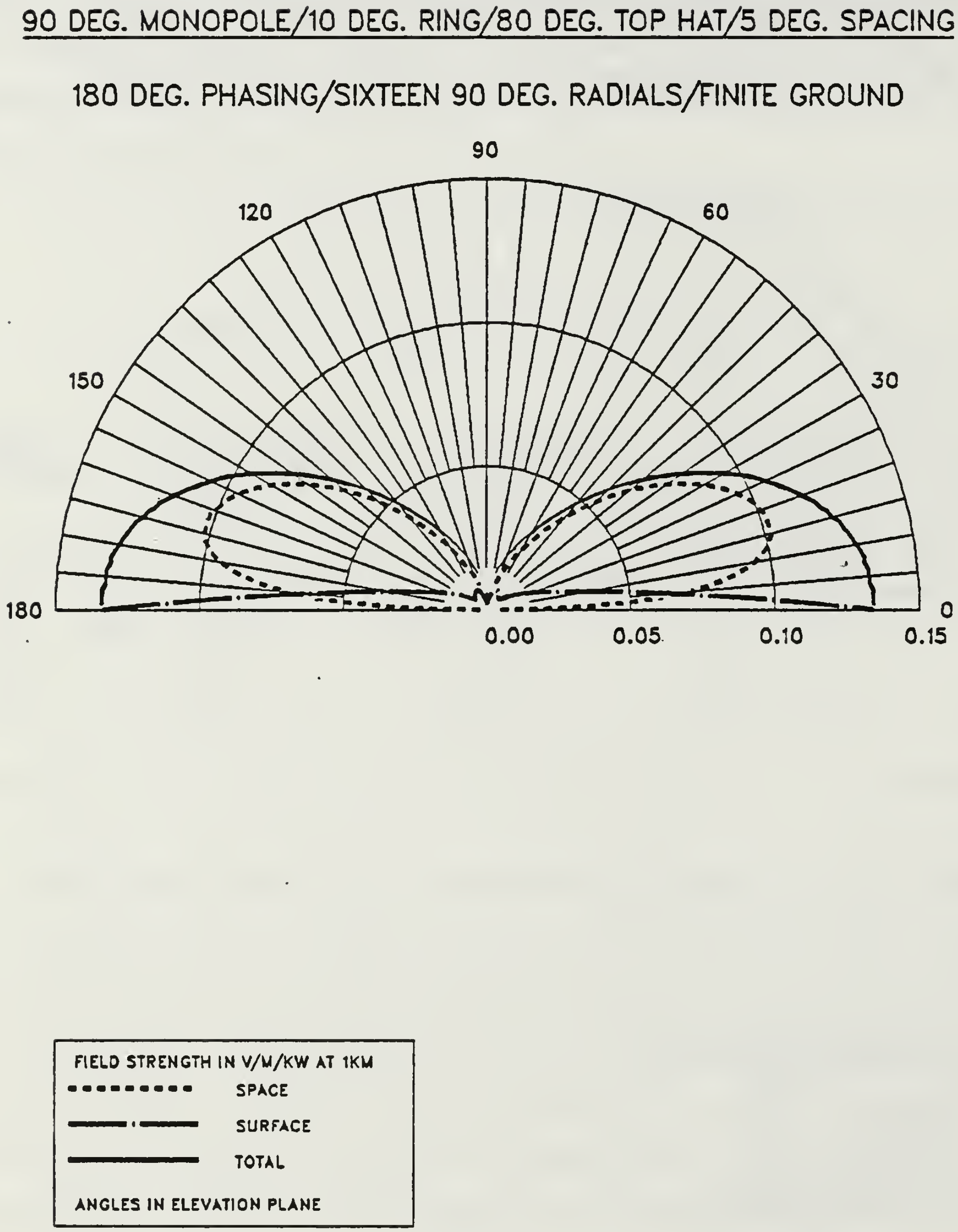


Figure 2.17 Radiation Pattern - 20 Deg. High Fence.

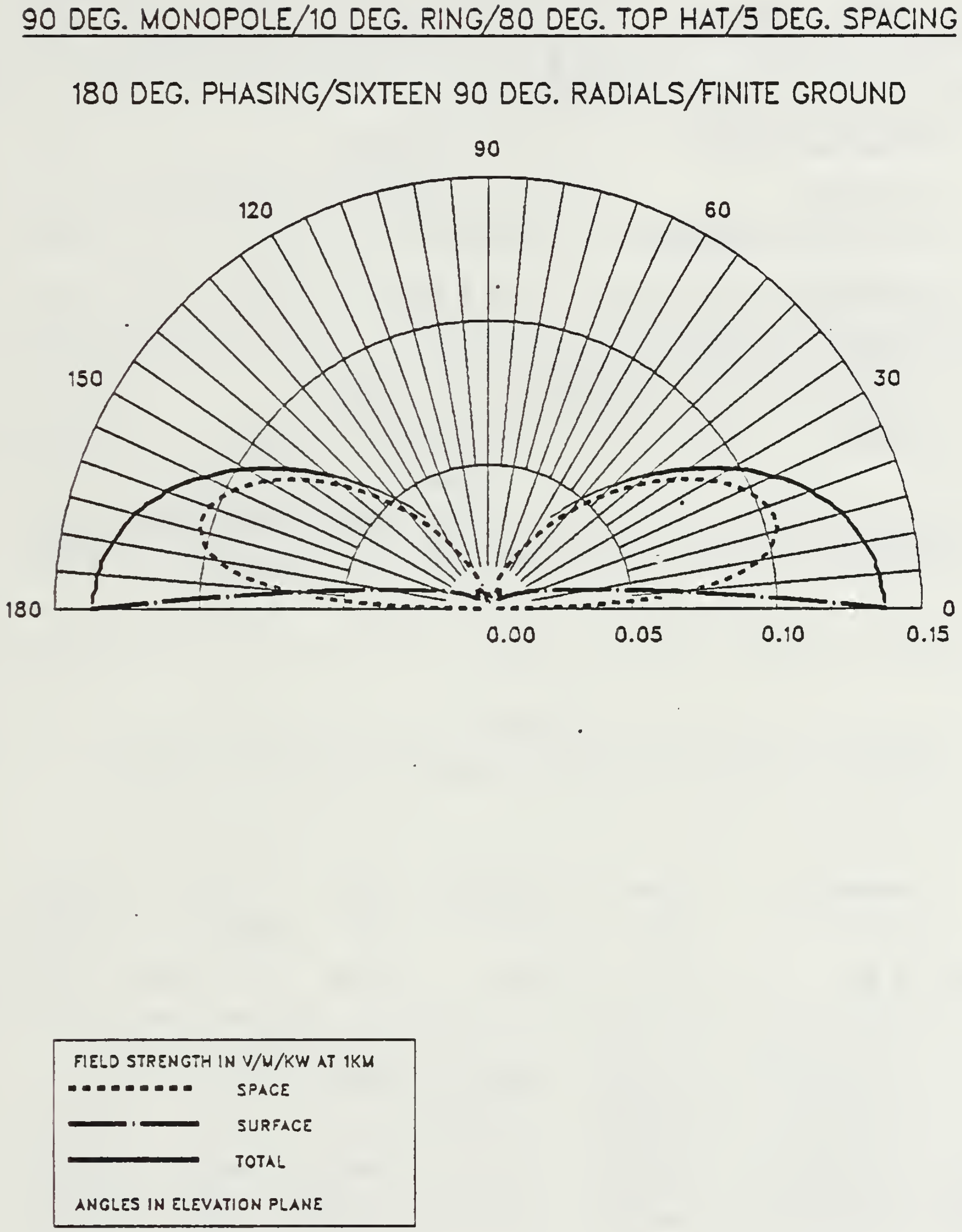


Figure 2.18 Radiation Pattern - 30 Deg. High Fence.

6. Effect of Varying the Ground Conductivity

For an AM broadcast antenna the space current finds its return path to the excitation source through the ground plane surrounding the earth. When operating at high power levels, large current densities are encountered. Therefore the strength of the radiated field depends on the power absorbed by the lossy ground. Biby has modeled his proposed ASW antenna over a fair ground with a conductivity of 0.004 S/M [Ref. 2]. To study the effect of varying ground conductivity, Biby's proposed antenna was modeled with the following parameters:

monopole height	:	90 degrees
ring height	:	10 degrees (no top hat)
no. of buried radials	:	16
frequency	:	1 MHz
relative earth permitivity	:	15
drive currents phase difference	:	180 degrees
ground	:	perfect
		good (σ = 0.4 S/M)
		fair (σ = 0.004 S/M)
		poor (σ = 0.00004 S/M)

TABLE 7

EFFECT OF VARYING THE GROUND CONDUCTIVITY

σ in S/M	Monopole Z_i in Ω	Ring Z_i in Ω	Monopole P_i in W	Ring P_i in W	Ground Wave in mV/M	Space Wave in mV/M
∞	4.6+j52.3	-1.6-j2768	5023.8	-4524.4	395.1	
0.4	31.2-j65.7	0.9-j2753	467.2	32.8	44.1	41.9
0.004	2.1+j46.8	7.2-j2753	52.6	447.4	46.5	33.6
0.00004	1.8+j46.9	2.4-j2774	121.7	378.3	73.6	66.8

As we switch from perfect ground to real ground, much of the energy is absorbed into the ground. The drive point impedance is still much lower than that of the standard AM broadcast antenna, suggesting strong mutual impedance effects from the very close element spacing.

7. Summary of Analysis - Biby's Proposed Design

After extensive modeling of the proposed anti-skywave AM broadcast antenna, the results can be summarized as following:

- There is overall attenuation of both the sky wave and the ground wave
- Lossy ground is absorbing most of the energy.
- The cancelling phase difference between the monopole and the ring current drives is not in the range of 170 degrees to 185 degrees.
- The proposed ASW antenna with an 80 degree long ring top hat and a drive currents phase difference of 180 degrees gives the best value (113.3 mV/M) of the ground wave (Table 5), which is still much below the 273.9 mV/M (Table 2) produced by the standard AM broadcast antenna without any ASW structure.
- The proposed antenna with $\lambda/4$ top hat is highly sensitive to the drive phase (Table 5 and Figures 2.12 - 2.15). This suggests a potential unstable performance in the proposed design.
- The 10 degree high fence at quarter wave from the origin does not help appreciably in attenuating the ring ground wave without affecting the monopole ground wave. As the fence height is increased the fence starts reradiating.

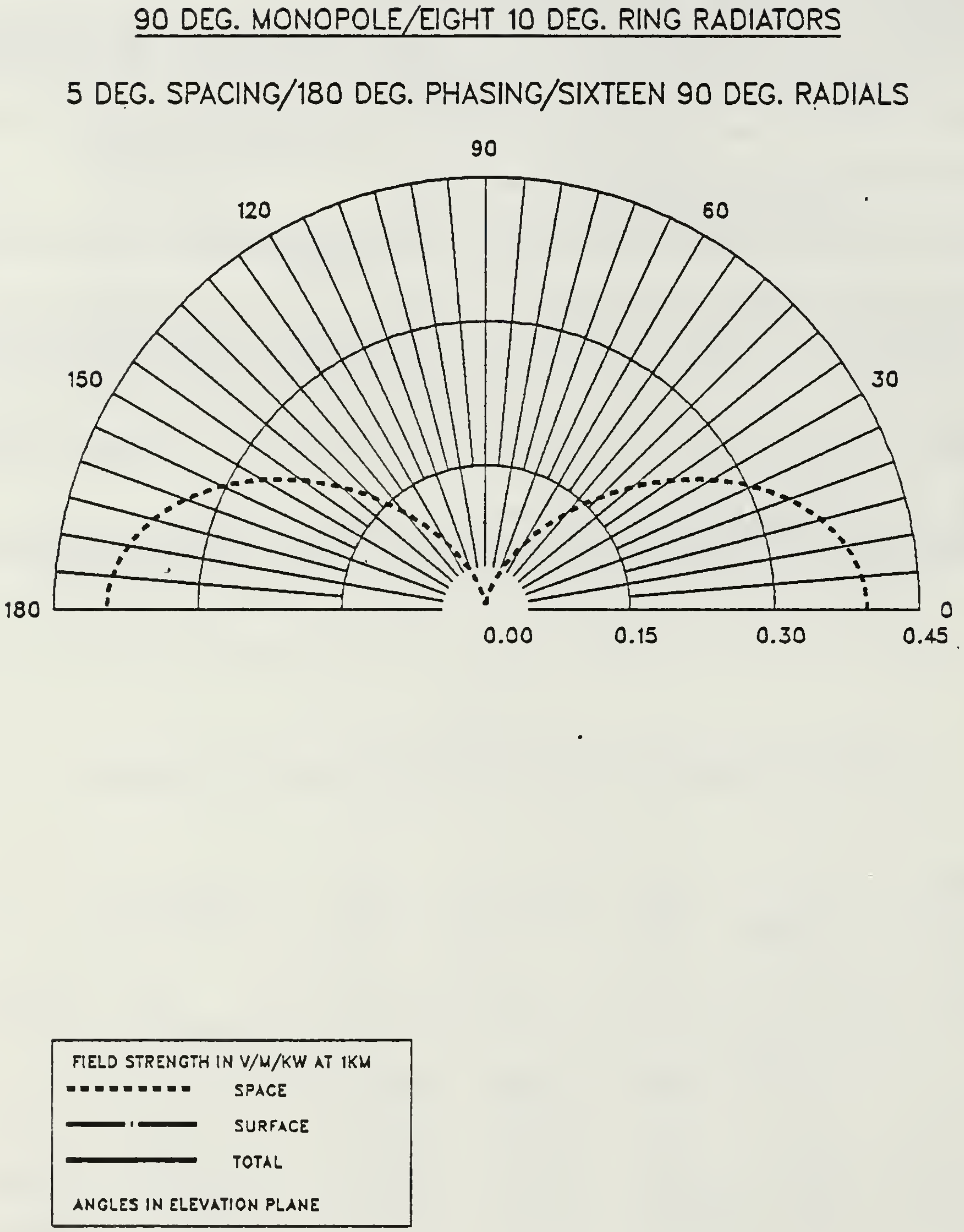


Figure 2.19 Radiation Pattern - Perfect Ground.

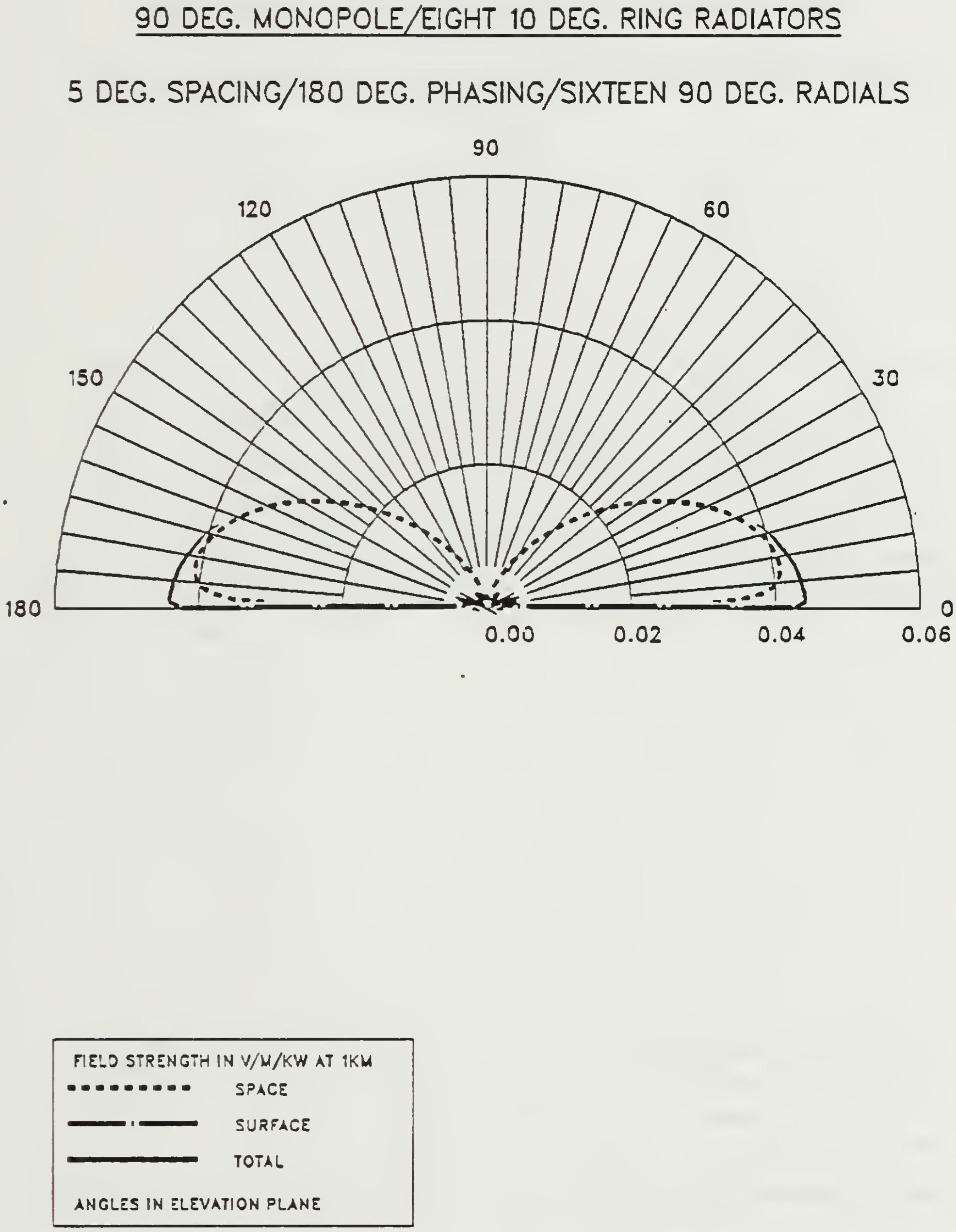


Figure 2.20 Radiation Pattern - Good Ground (σ = 0.4 S/M).

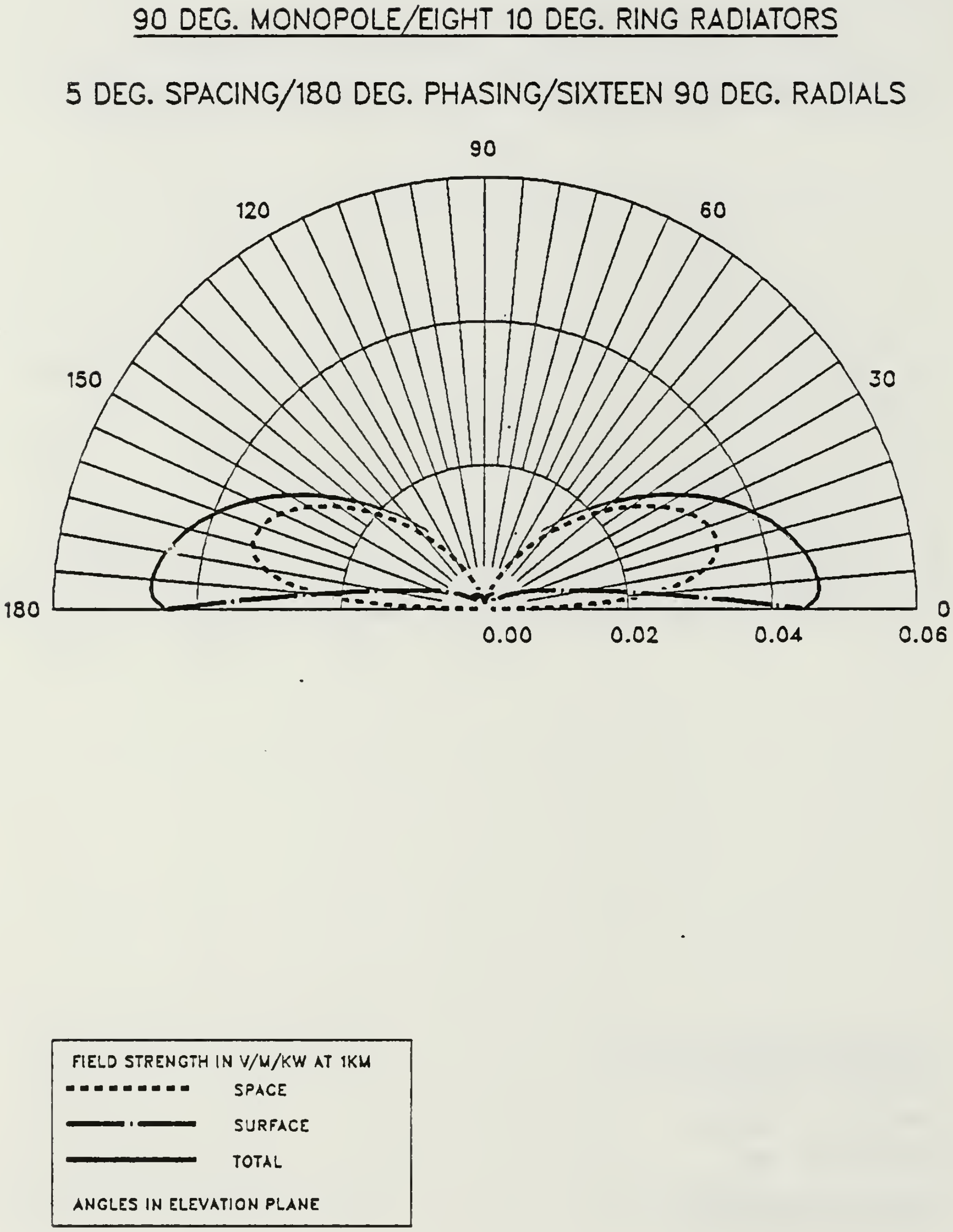


Figure 2.21 Radiation Pattern - Fair Ground (σ = 0.004 S/M).

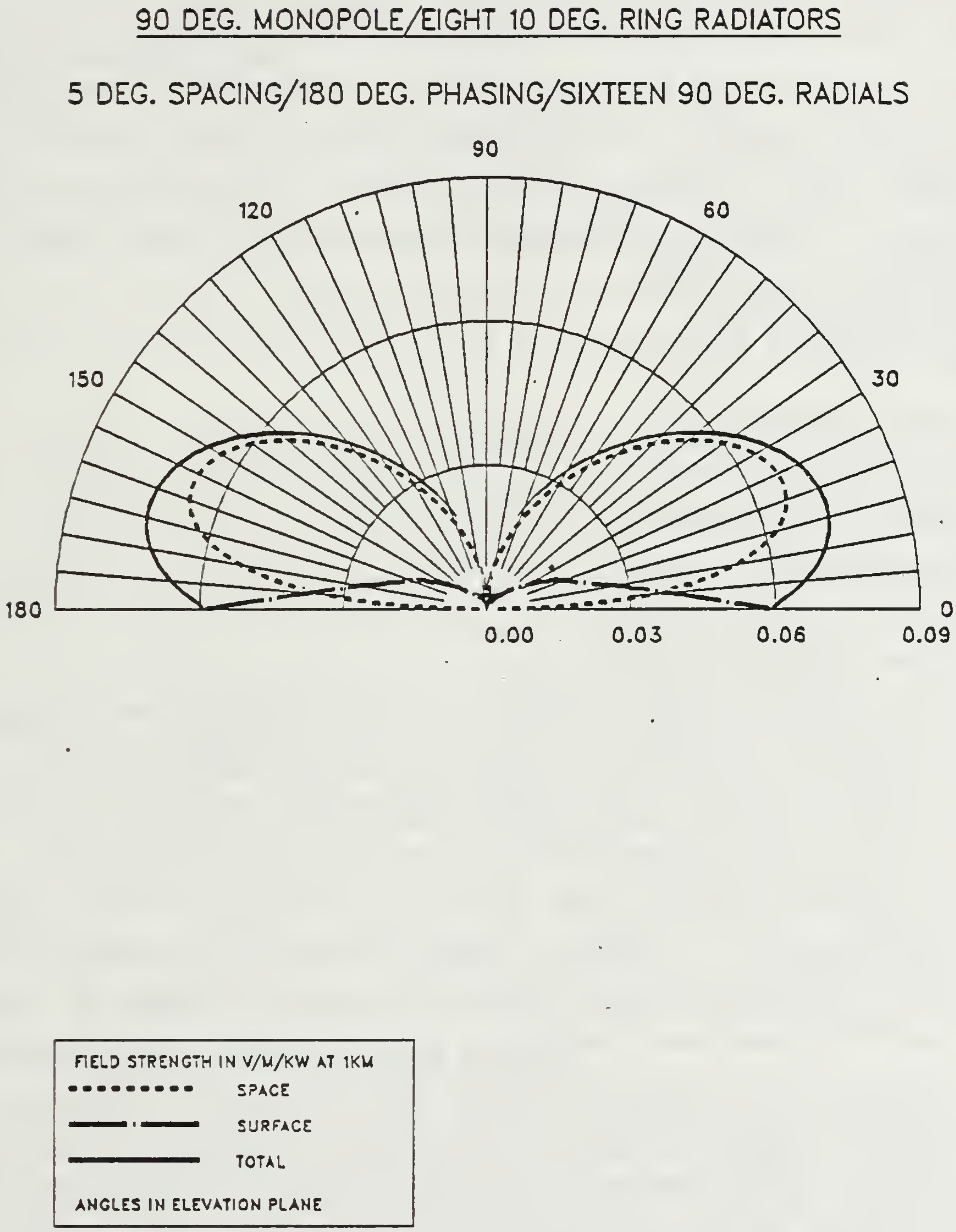


Figure 2.22 Radiation Pattern - Poor Ground (σ = 0.00004 S/M).

III. GENERIC RADIATOR STUDY

The extensive analysis of Biby's proposed anti-skywave AM broadcast antenna did not show the desired results of ground wave enhancement and sky wave suppression. The structure was found to be attenuating both the ground wave and the sky wave by more than 6 dB as compared with the standard AM broadcast antenna without any ASW capability. As Biby's antenna consists of tightly coupled (5 deg. spacing) short antennas operating over finite ground, it was appropriate to study generic radiators to understand the reasons for the behaviour of Biby's design. The following structures were modeled:

- 20 degree isolated dipole
- 180 degree isolated dipole
- 20 degree coupled dipoles
- 180 degree coupled dipoles
- 10 degree isolated monopole
- 90 degree isolated monopole
- 10 degree coupled monopoles
- 90 degree coupled monopoles

For the coupled monopoles a spacing of 5 degrees was selected and a cancelling phasing of 175 degrees was used to place a null in the vertical radiation pattern on one side of the structure. The NEC wire models of these structures are shown in Figure 3.1 to Figure 3.6. The structures were modeled in free space, over perfect ground, over finite ground and then gradually raised over finite ground to observe the effect of finitely conductive earth. The listings of typical data sets are in Appendix B.7 to Appendix B.22. The resulting radiation patterns are shown in Appendix A. In each case the value of the ground wave field strength was compared with the perfect ground case as a reference. The corresponding curves are shown in Figure 3.7 to Figure 3.11.

This study of isolated and coupled radiators proved very useful in finding answers for the behaviour of Biby's antenna. It was observed that the tightly coupled short radiators over finite ground are the most inefficient (Figure 3.11). Among all structures modeled, 10 degree coupled short radiators showed the maximum attenuation over finite ground (-29.5 dB at 5 deg. spacing). Much of the power seems

to be absorbed by the ground. The coupled 10 degree monopoles improve slightly as they are raised over finite ground (Figure 3.10). When elevated beyond 5 degrees, the ground wave starts disappearing (Figure A.64-66). The 90 degree monopoles perform better than 10 degree monopoles over finite ground (Figure 3.9). Non-resonant 10 degree monopoles have to be raised fairly high in order to achieve a resonable power gain, whereas the resonant 90 degree monopoles do not have to be as high to achieve the same improvement in gain.

Coupled 20 degree dipoles perform better than coupled 10 degree monopoles (Figure 3.11). For the coupled 10 degree monopoles over finite ground, the magnitude of current in all the six radials is very small (in fraction of an Amp), and it has a maximum value of 12 Amps for the vertical monopoles. It increases as the structure is elevated. This shows that the large attenuation for coupled 10 degree monopoles over finite ground is not due to I^2R loss, but it is the field which is coupling with the ground.

In chapter II the quarter wave standard AM broadcast antenna over finite ground was modeled with 120 buried radials and the ground wave field strength was 273.9 mV/M (Table 2). Whereas 90 degree monopole with four radials raised 0.5 degree over finite ground gives a ground wave field strength of 244.14 mV/M (Figure A.37). It implies that the 90 degree monopole over finite ground does not require a large number of buried radials, rather four radials raised over finite ground are enough.

Though this study answers many of the desired questions, there are still areas to be investigated. To further improve knowledge of the behaviour of such structures, more research can be done. In this study to see the behaviour of coupled radiators, 90 - 90, and 10-10 degree monopole pairs were used. The 90-90 degree structure performed well, whereas the 10-10 degree structure was very inefficient. As Biby's design not only involves a coupling between the short radiators themselves, but also with the 90 degree monopole at the origin, it is worthwhile to study the effect of tight coupling between a 10 degree short radiator and the 90 degree monopole.

The radials in the ground plane for the monopoles seem to play a significant role in efficiency. The geometry of the radials for isolated and coupled monopoles were selected for the desirable property of symmetry needed for efficient computation by NEC. Other geometries could be used to see the effect on wave launching capabilities. To study the effect of earth, the structures were raised over the finite ground. A logical extension of this is to see what happens when the ground plane radial wires for the

monopoles are gradually immersed into the finite ground. The monopoles modeled in this study were 10 degree and 90 degree high. It might be useful to examine a 180 degree monopole with four radials in the ground plane. This antenna has a very high input impedance and would have very low radial wire currents at the base of the antenna. If ground losses are largely due to coupling of radial currents into the lossy interface, anything which reduces radial currents should improve efficiency.

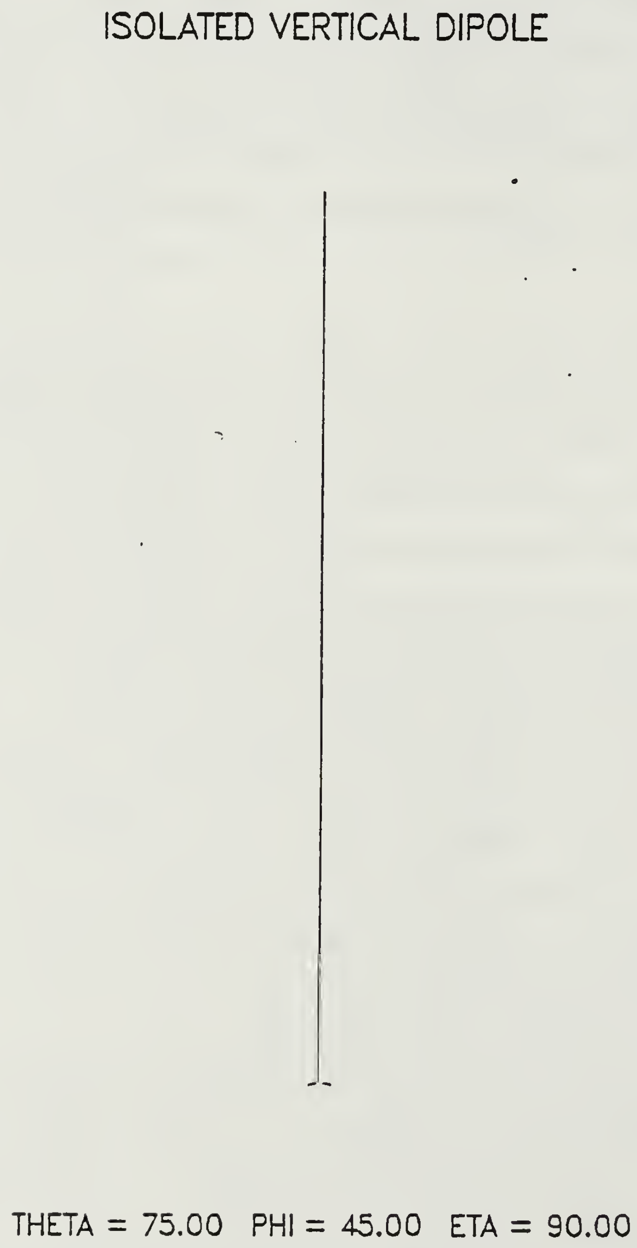


Figure 3.1 Isolated Dipole.

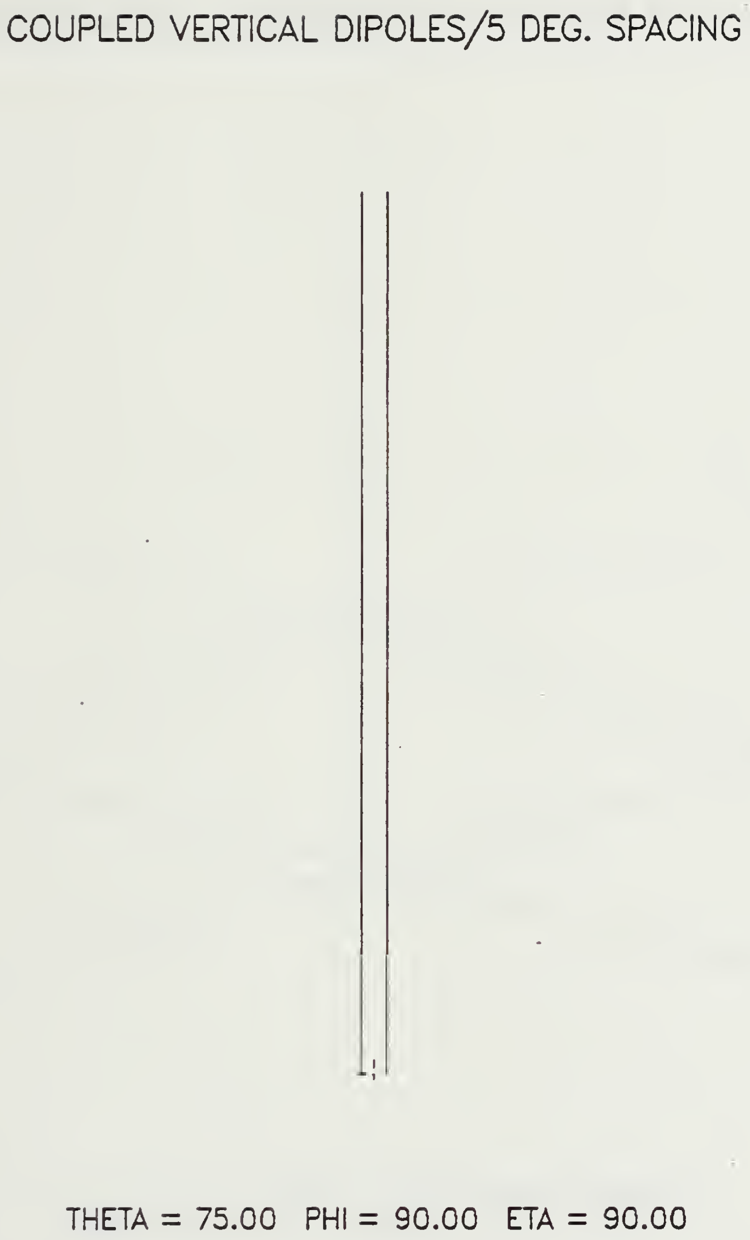


Figure 3.2 Coupled Dipoles.

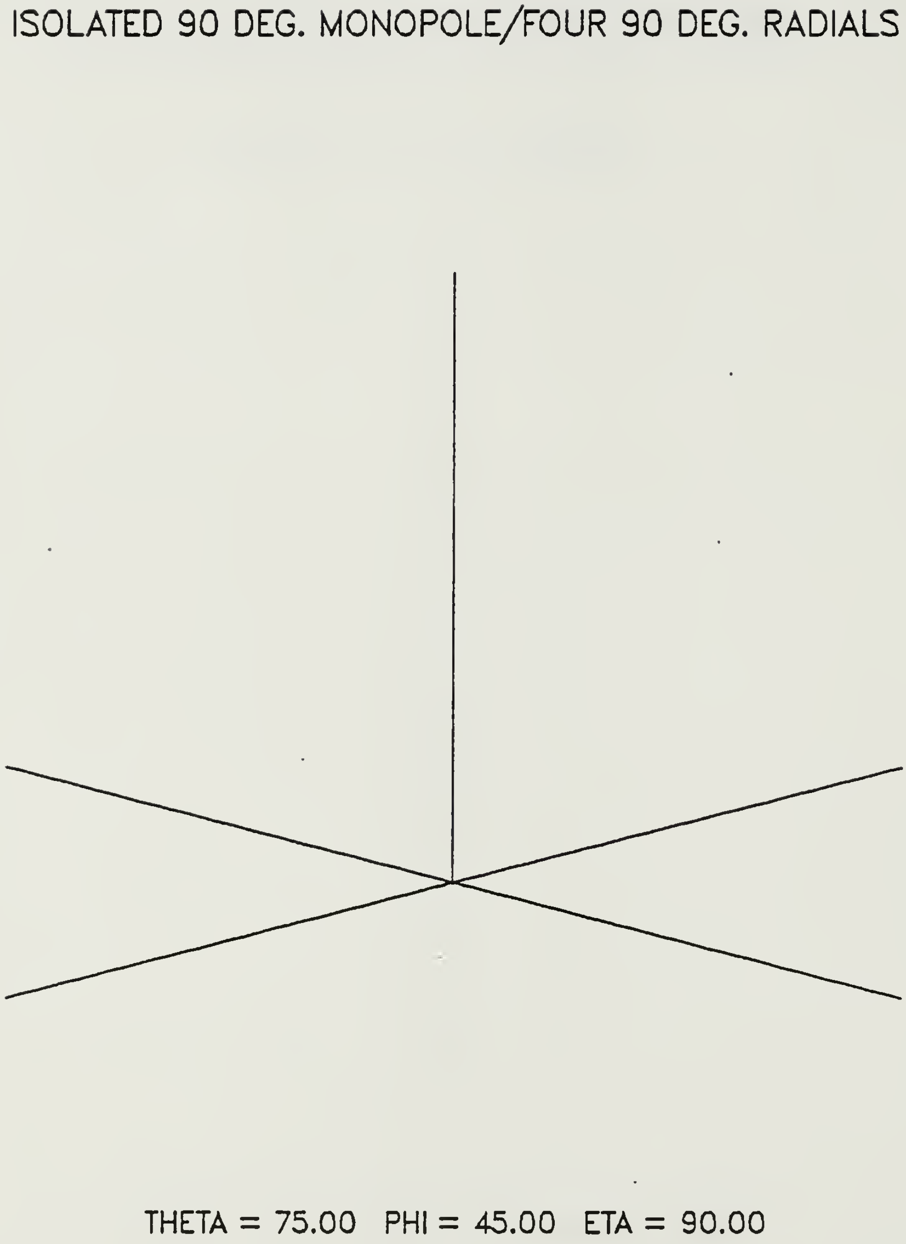


Figure 3.3 Isolated 90 Deg. Monopole.

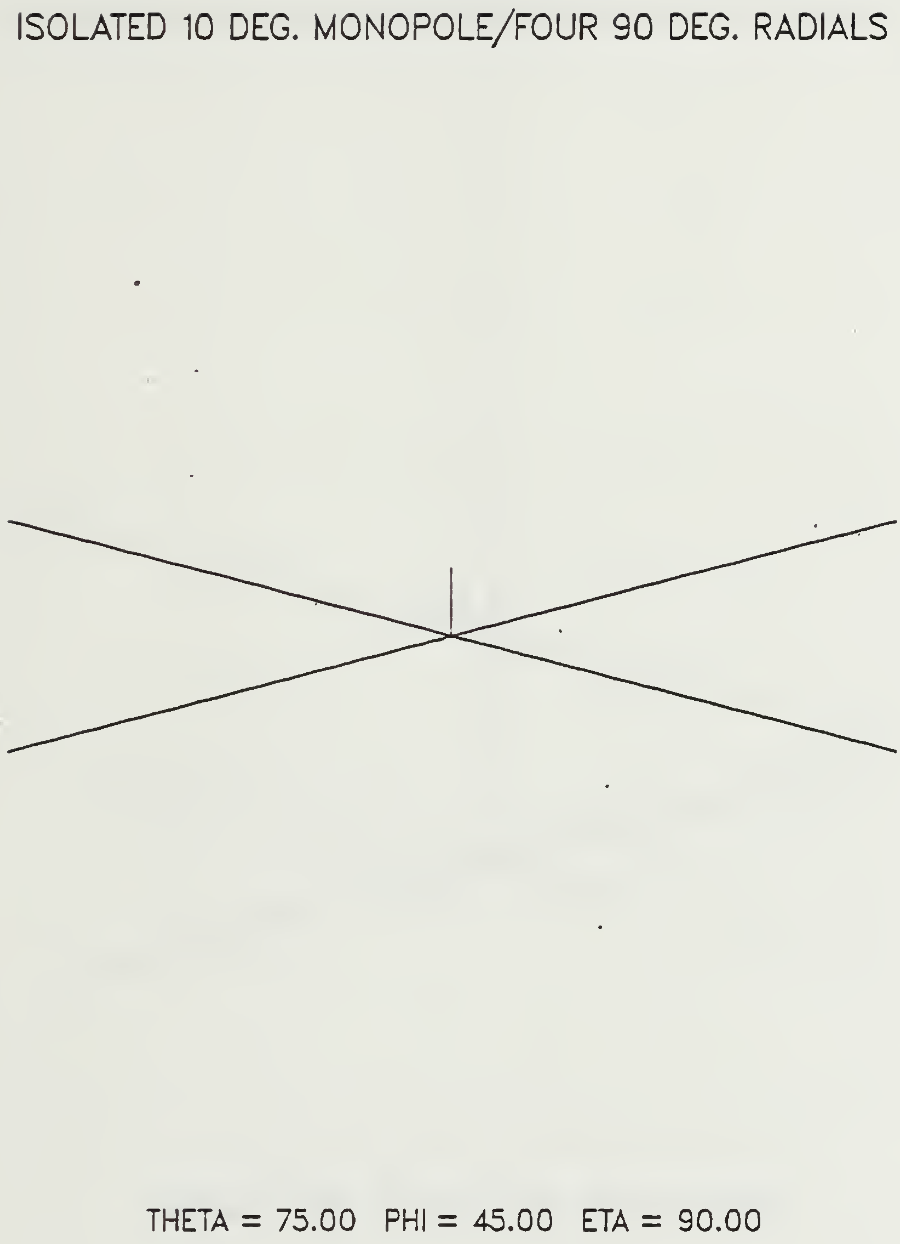


Figure 3.4 Isolated 10 Deg. Monopole.

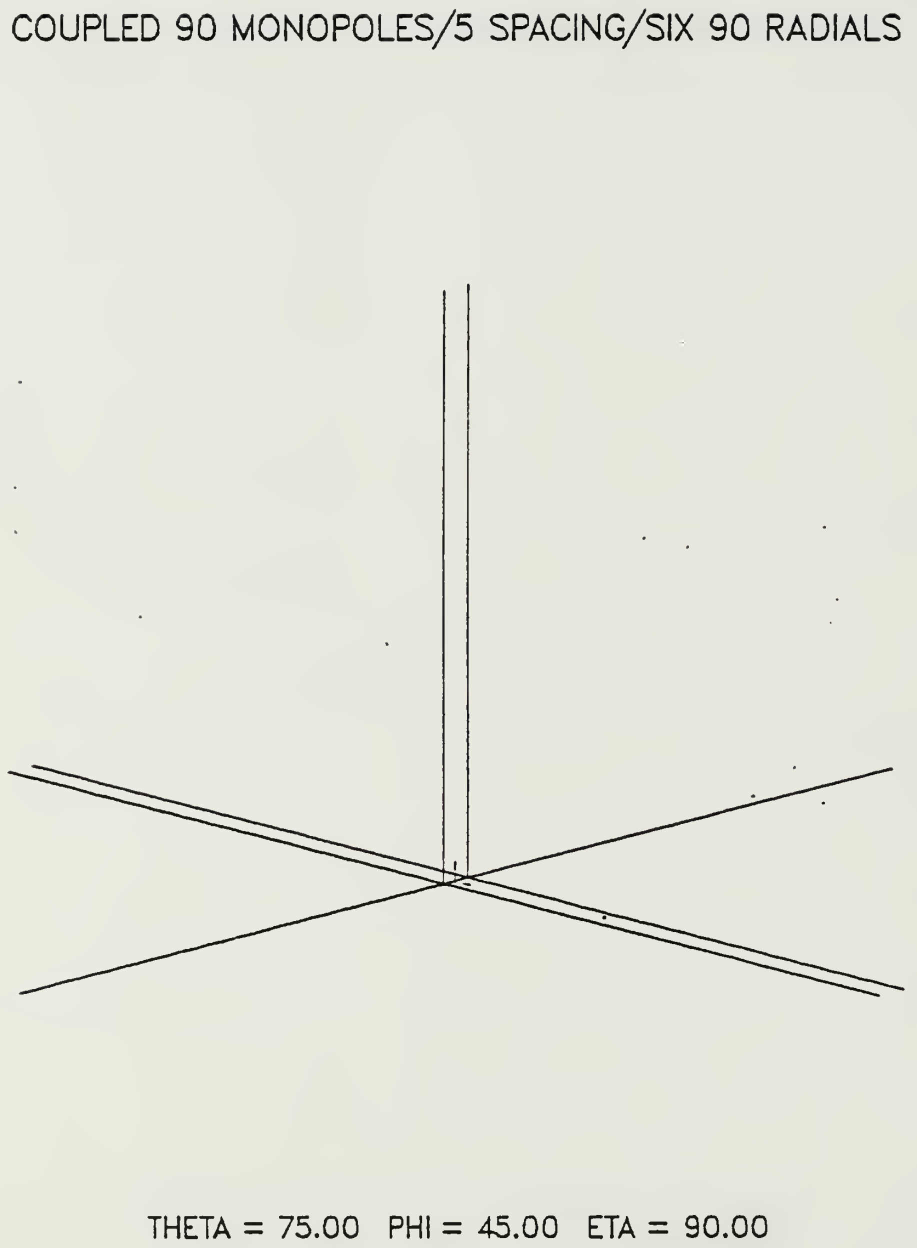
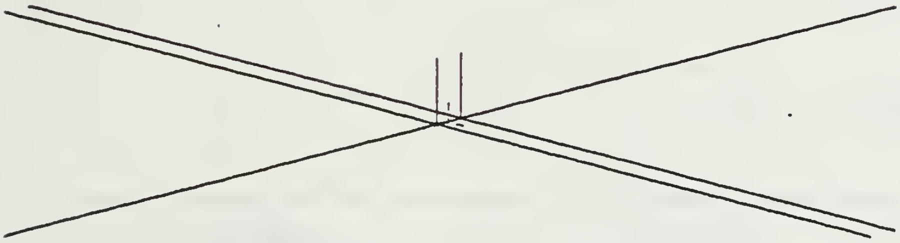


Figure 3.5 Coupled 90 Deg. Monopoles.

COUPLED 10 MONOPOLES/5 SPACING/SIX 90 RADIALS



THETA = 75.00 PHI = 45.00 ETA = 90.00

Figure 3.6 Coupled 10 Deg. Monopoles.

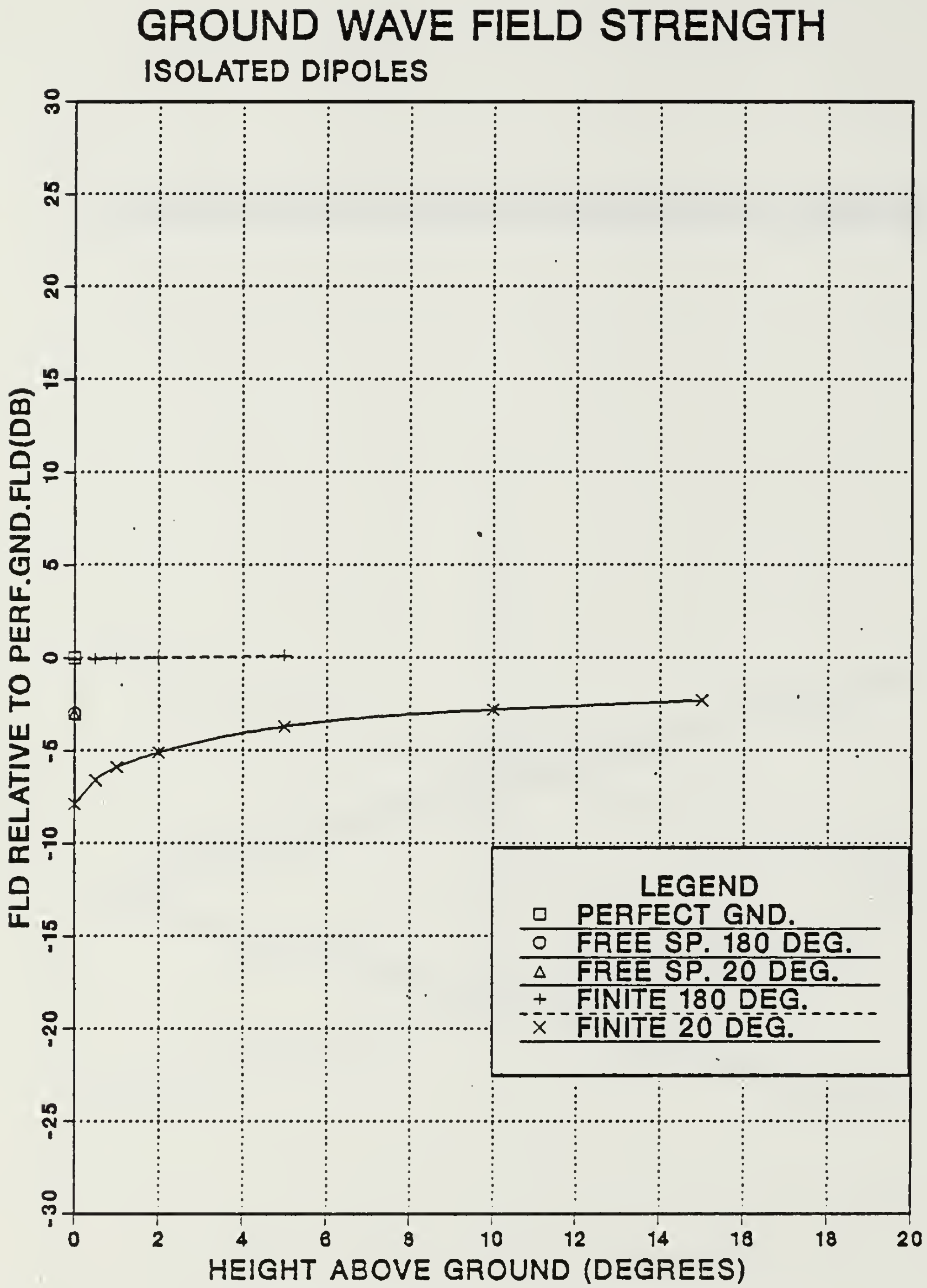


Figure 3.7 Ground Wave Field Strength For Isolated Dipole.

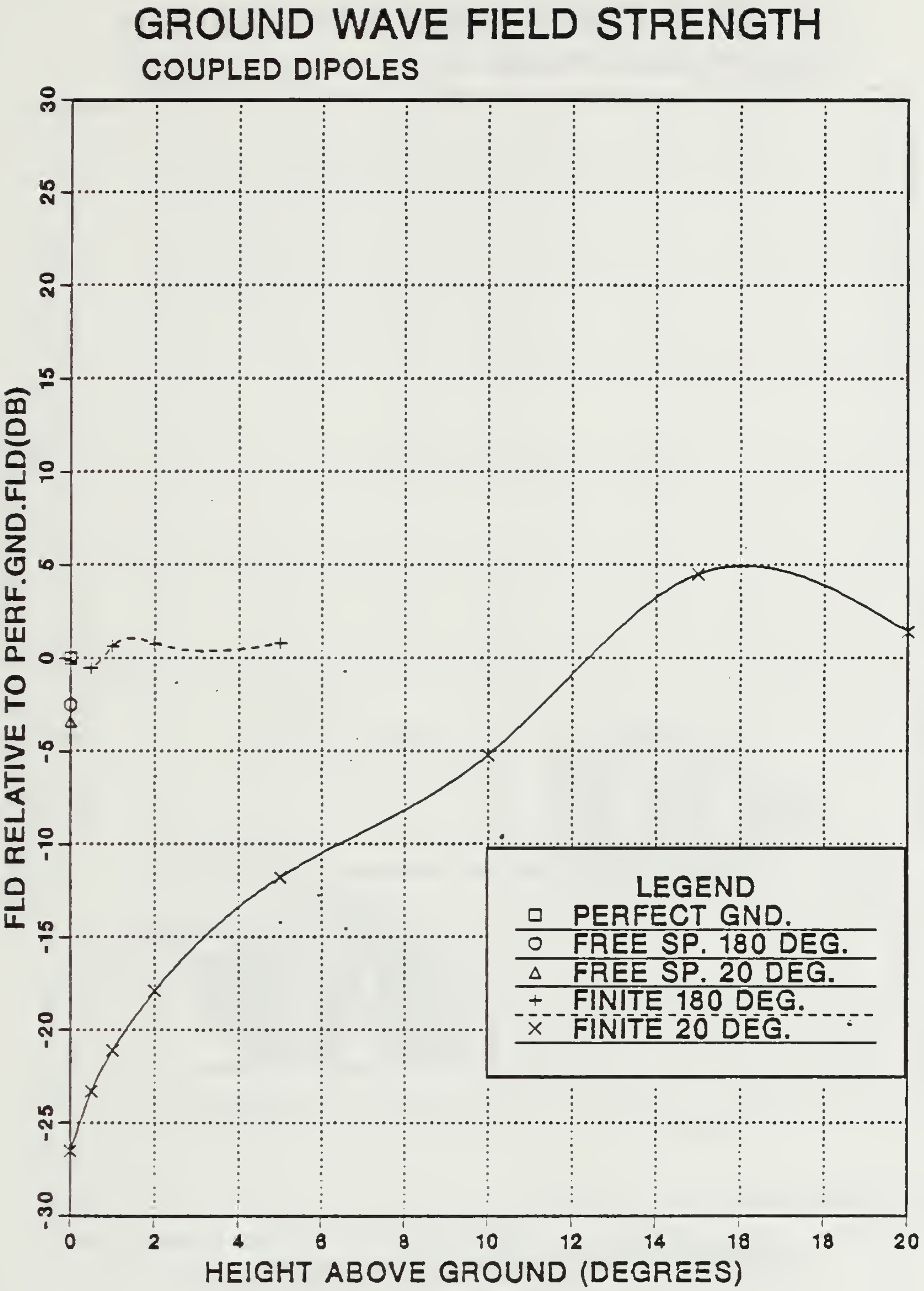


Figure 3.8 Ground Wave Field Strength For Coupled Dipoles.

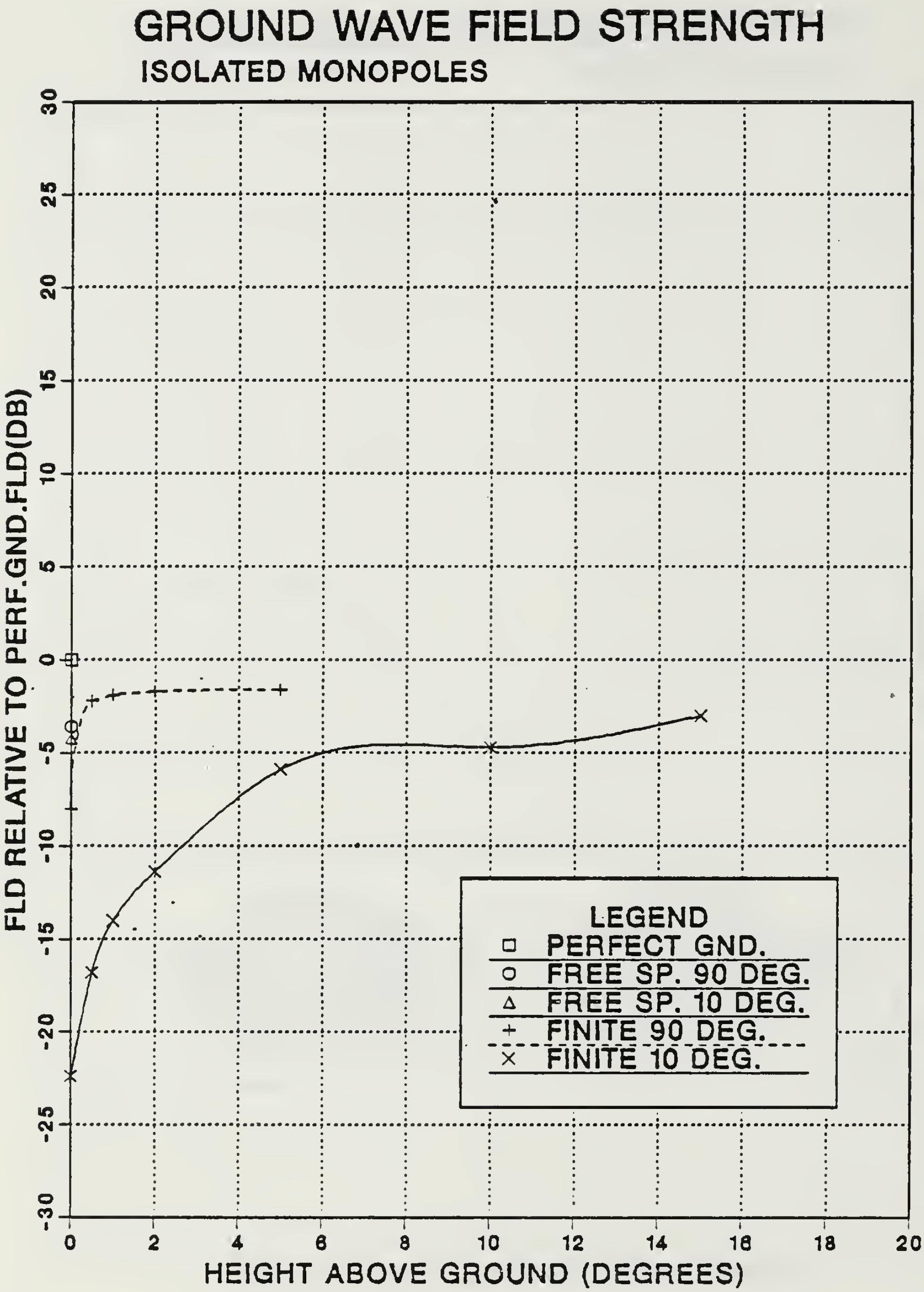


Figure 3.9 Ground Wave Field Strength For Isolated Monopole.

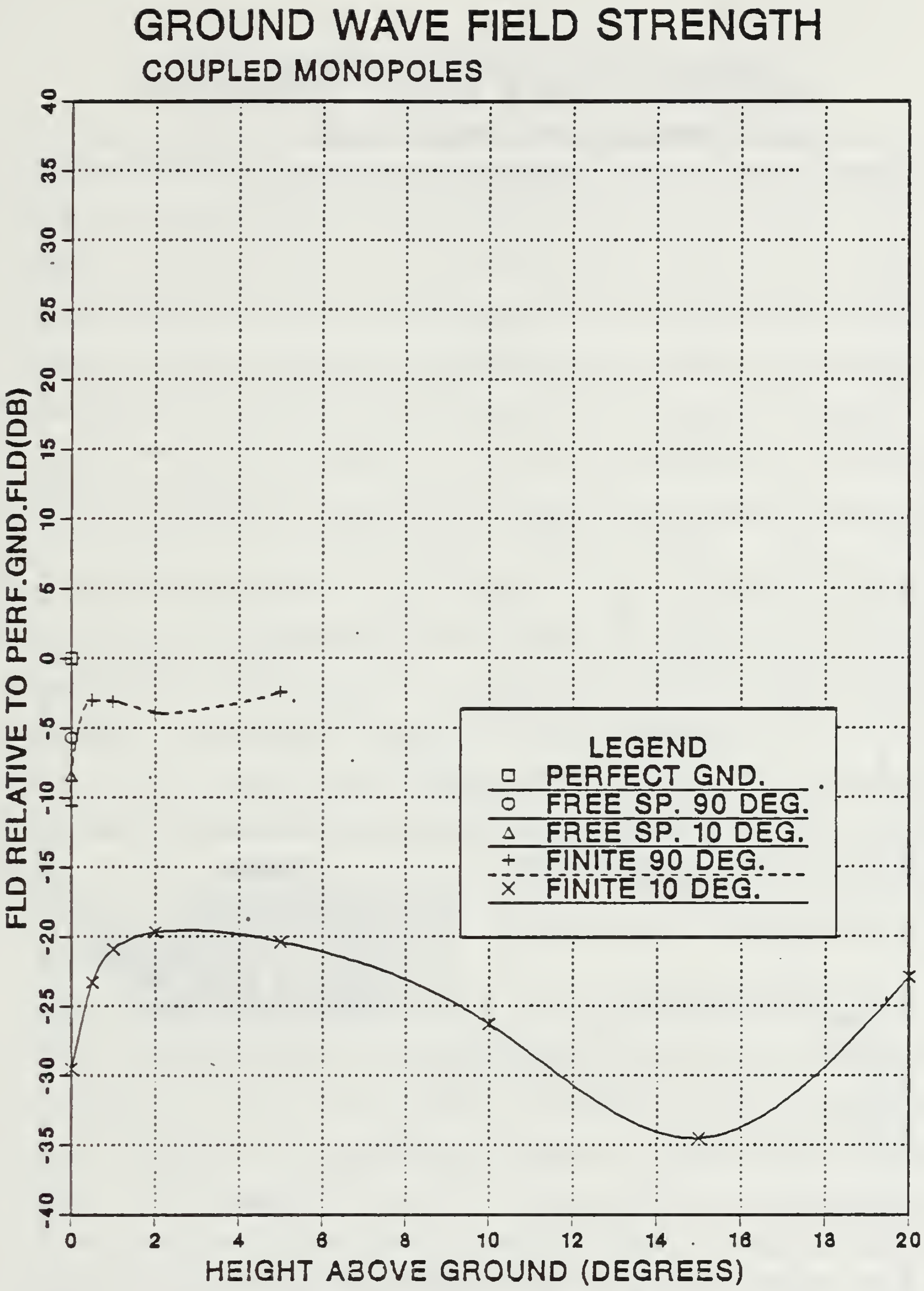


Figure 3.10 Ground Wave Field Strength For Coupled Monopoles.

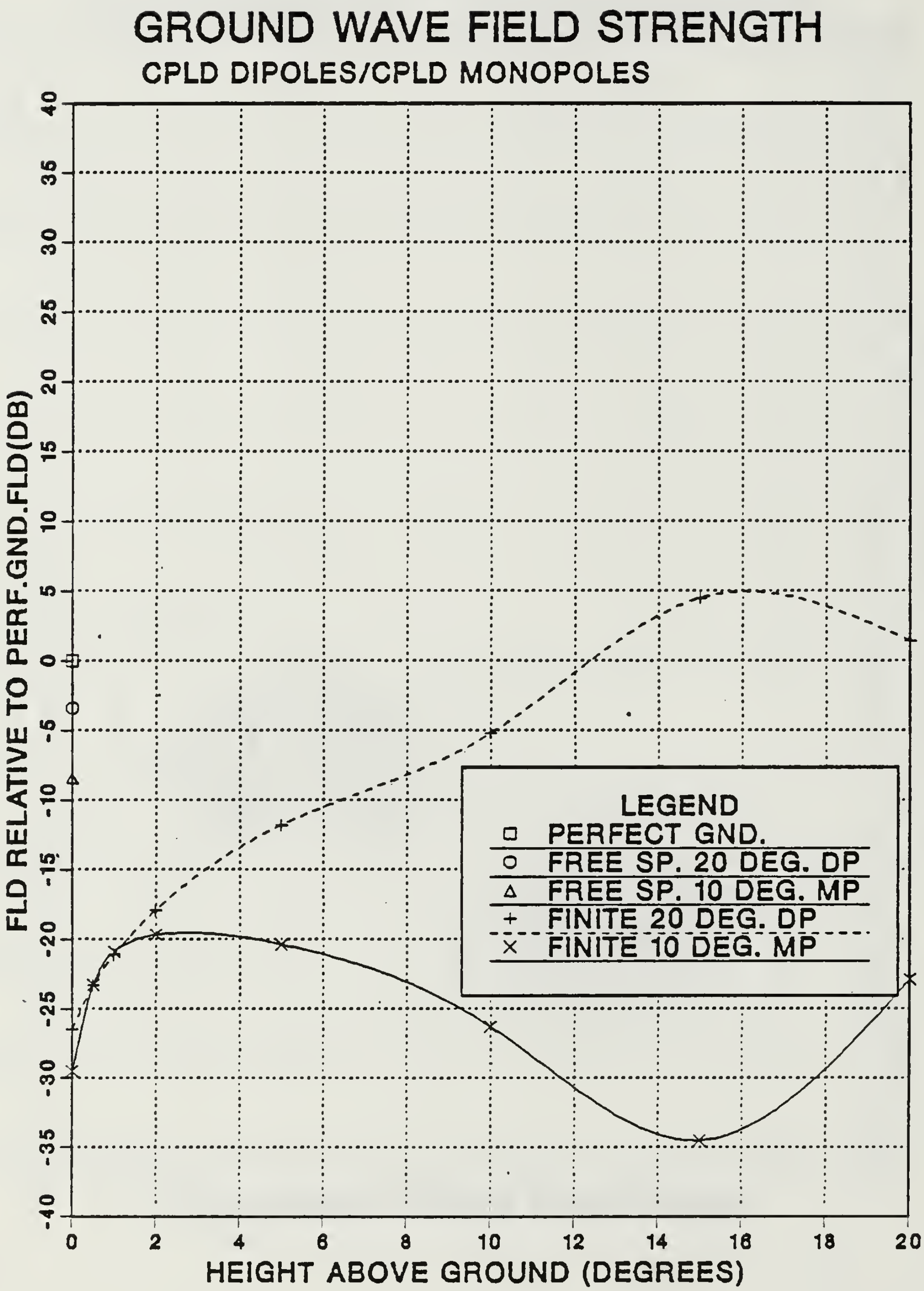


Figure 3.11 Ground Wave Field Strength For Coupled Dipoles and Coupled Monopoles.

IV. CANDIDATE ASW STRUCTURES

From the analysis of Biby's proposed design it has been observed that the phasing of the driven elements is the most important factor in the design of an anti-skywave AM broadcast antenna. The generic study of the coupled radiators shows that a null can be placed easily in the radiation pattern if the coupled structure consists of only two radiators. The null can be steered in the elevation plane by taking into account the path length difference while phasing the radiator drives. The problem becomes complicated when the structure consists of more than two elements.

A design method exists [Ref. 3], to improve the directivity in the vertical plane using short ring radiators. A short radiator is placed in the center and a set of short radiators are placed in concentric rings around the central radiator. The current amplitudes and the phasings are well defined for the individual elements [Ref. 3: p 817,818]. The phase is varied progressively between the adjacent elements of a ring in such a manner that the total phase shift around each ring is an integer multiple of 360 degrees, and the total phase shift between the rings is the same.

There are two types of such antennas, type J_0 and type J_n. The type J_0 consists of multiple concentric rings (Figure 4.1), with all elements in a single ring having the same phase. The J_n configuration consists of only a single ring (Figure 4.2), where the phase of the individual elements is varied such that the total phase shift is n cycles, where n is an integer.

The problem in applying this concept to the AM broadcast antenna is that the antenna is not electrically short. However to achieve ground wave enhancement and sky wave cancellation, some relations can be investigated based on these concepts for the phasing of the elements when the central radiator is a quarter wave monopole as in the standard AM broadcast systems. It should also be considered that the aforementioned directive antennas are only theoretical and are assumed to be operating over perfect ground. As it has been observed in the generic study of tightly coupled short radiators, they are highly inefficient over finite ground, therefore any attempt to improve directivity in the vertical plane using such a structure may not produce the desired results.

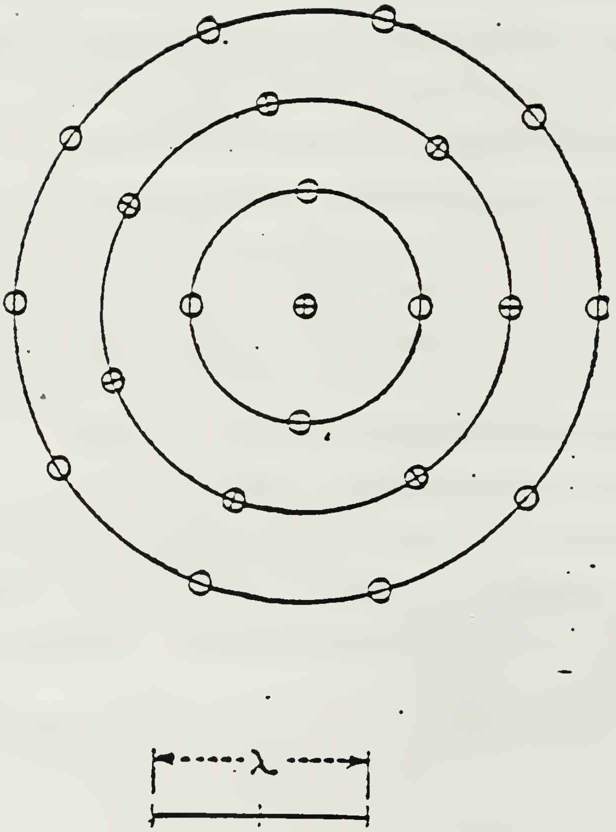


Figure 4.1 J_0 Antenna - Plan view.

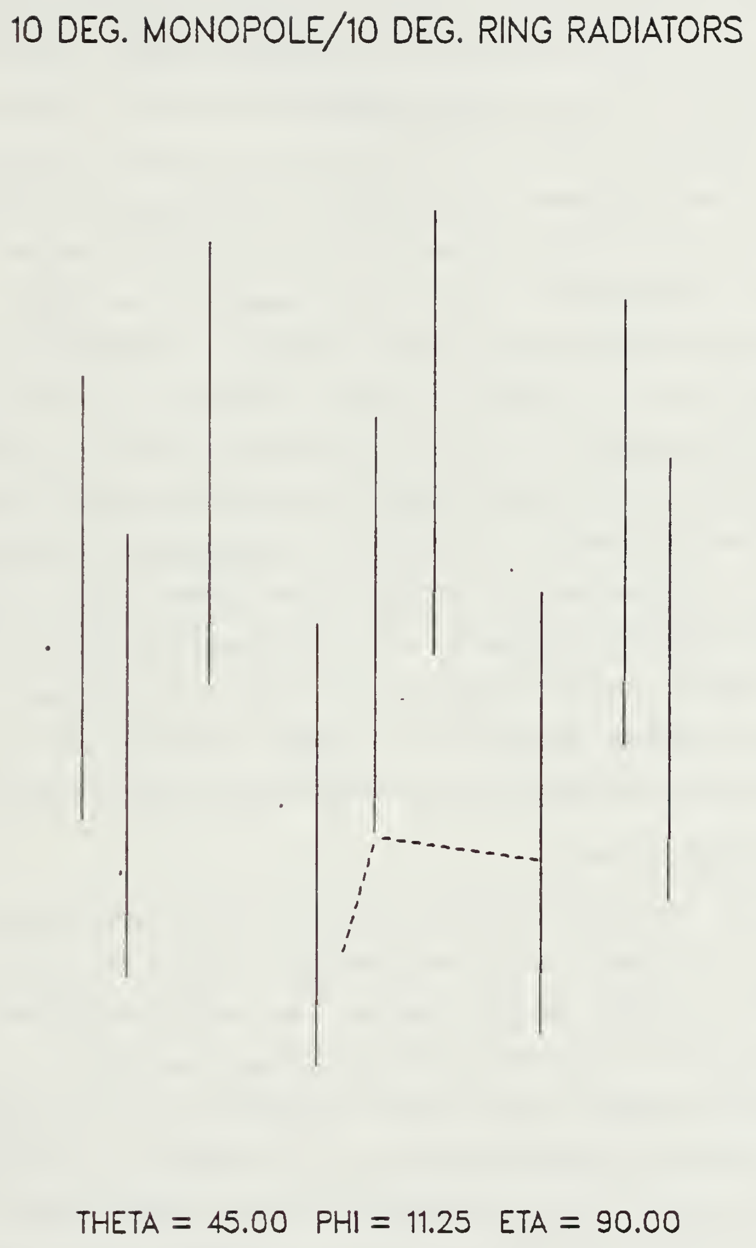


Figure 4.2 J_n Antenna.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This study has carried out an in depth numerical analysis of the design proposed by Richard L. Biby for the anti-skywave AM broadcast antenna. The proposed design was modeled using the Numerical Electromagnetic Code (NEC). There was an overall attenuation of radiation and the NEC results were not close to the proposed ones. Later the effects of varying phase, top hat length, fence height and ground conductivity were studied. The quarter wave top hat with a phasing of 180 degrees seemed to be better than other configurations. Since Biby's design involves tightly coupled short radiators operating over finite ground, to find answers for the behaviour of this design, a generic radiator study was done. The generic radiator study proved successful in finding some of the reasons for the poor performance of Biby's proposed design. On the basis of this study, it is concluded that the design proposed by Richard L. Biby is not likely to achieve the desired characteristics of ground wave enhancement and sky wave cancellation. Any attempt to design an anti-skywave AM broadcast antenna employing tightly coupled short radiators over finite ground is likely to be unsuccessful. The analysis of Biby's proposed design and the results of the generic radiator study also reveal that cancelling phase with 90 degree monopole and 10 degree short radiators is not easily achieveable by the simplified design approach which was used.

B. RECOMMENDATIONS

This thesis has presented a fairly extensive study of isolated and tightly coupled vertical radiators in different lossy environments. Though the results explain the behaviour of Biby's proposed design, there are areas which need further study. Based on the observations made in this study, recommendations are made.

The phasing of elements is most critical in placing a null in the radiation pattern of an antenna consisting of multiple elements. The relation for a linear array is well defined. A problem arises when the elements are not placed linearly. Though the phasing formulas do exist for directive antennas consisting of short radiators placed in multiple concentric rings spaced reasonably apart [Ref. 3], they are not defined when the central radiator is a quarter wave monopole and the short radiators are tightly coupled. Therefore research needs to be done to find proper phasing criteria of such circular directive arrays.

Coupled short monopoles were seen to improve slightly in terms of power gain when they were elevated over finite ground. It is of interest to see the effects when the ground plane radials are gradually immersed into the finite ground. Since tightly coupled short radiators have been found to be highly inefficient over finite ground, it is recommended that a solution to the problem be sought without using these, if efficiency has precedence over directivity.

APPENDIX A
RADIATION PATTERN PLOTS - GENERIC RADIATOR STUDY

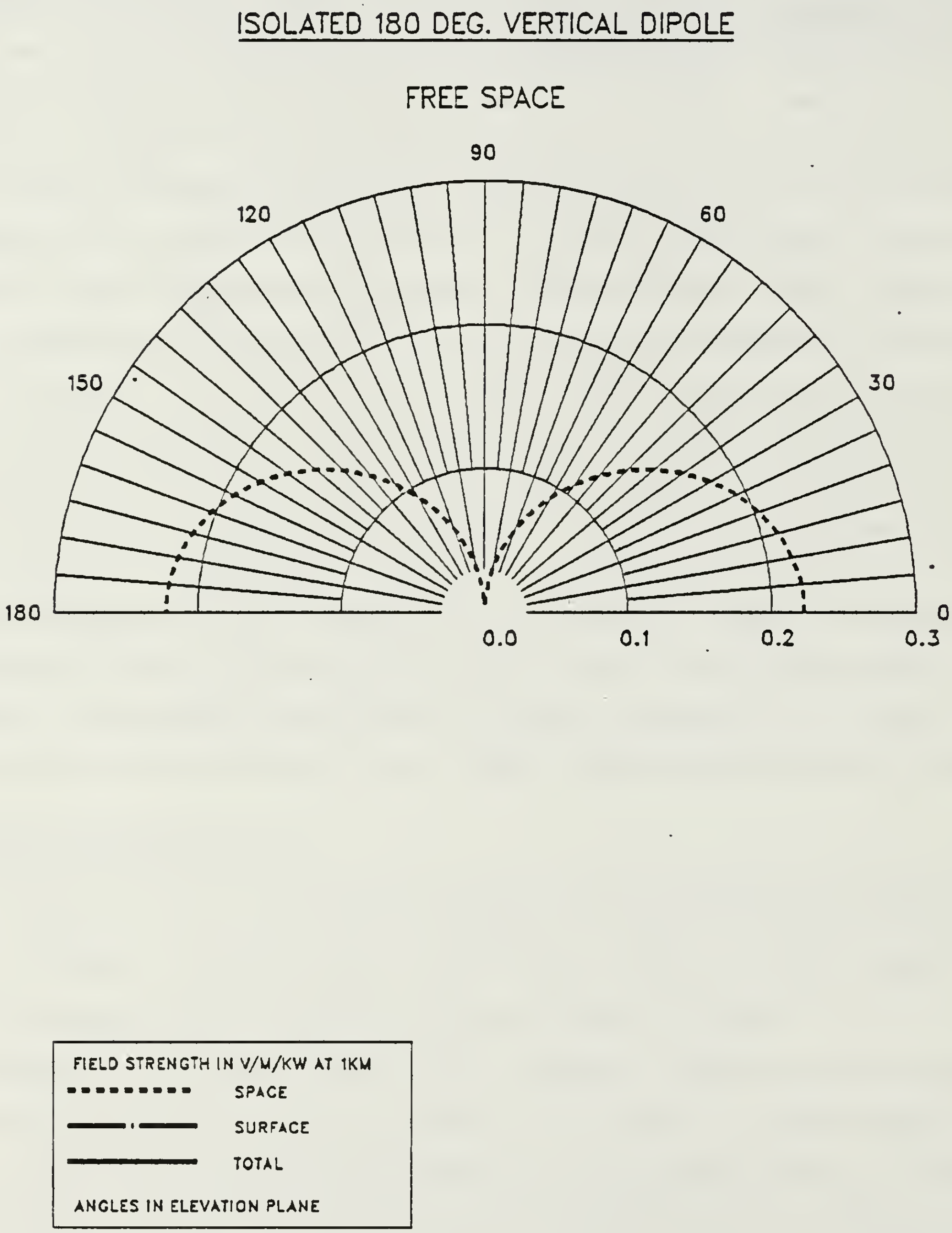


Figure A.1 Radiation Pattern - 180 Deg. Dipole in Free Space.

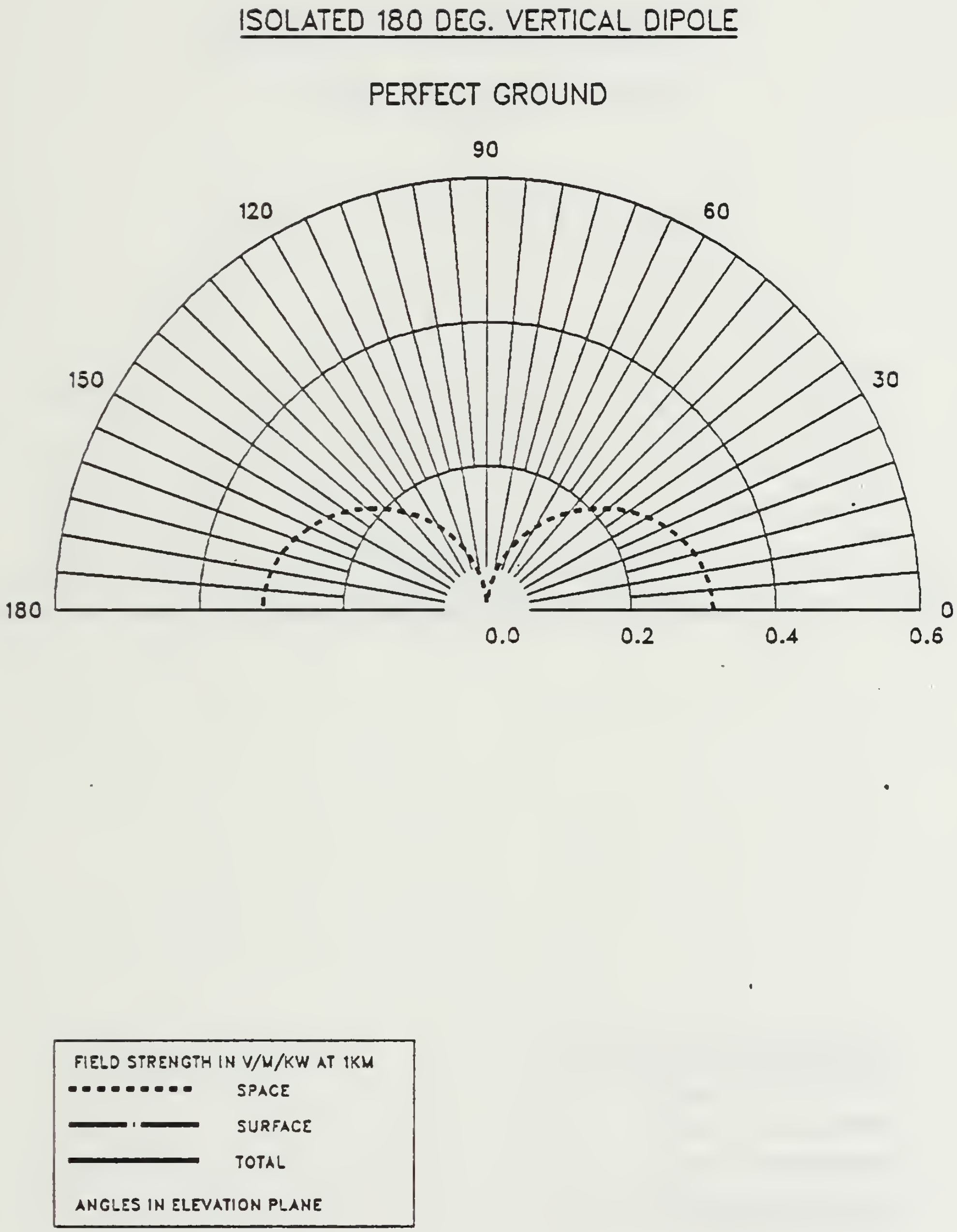


Figure A.2 Radiation Pattern - 180 Deg. Dipole over Perfect Ground.

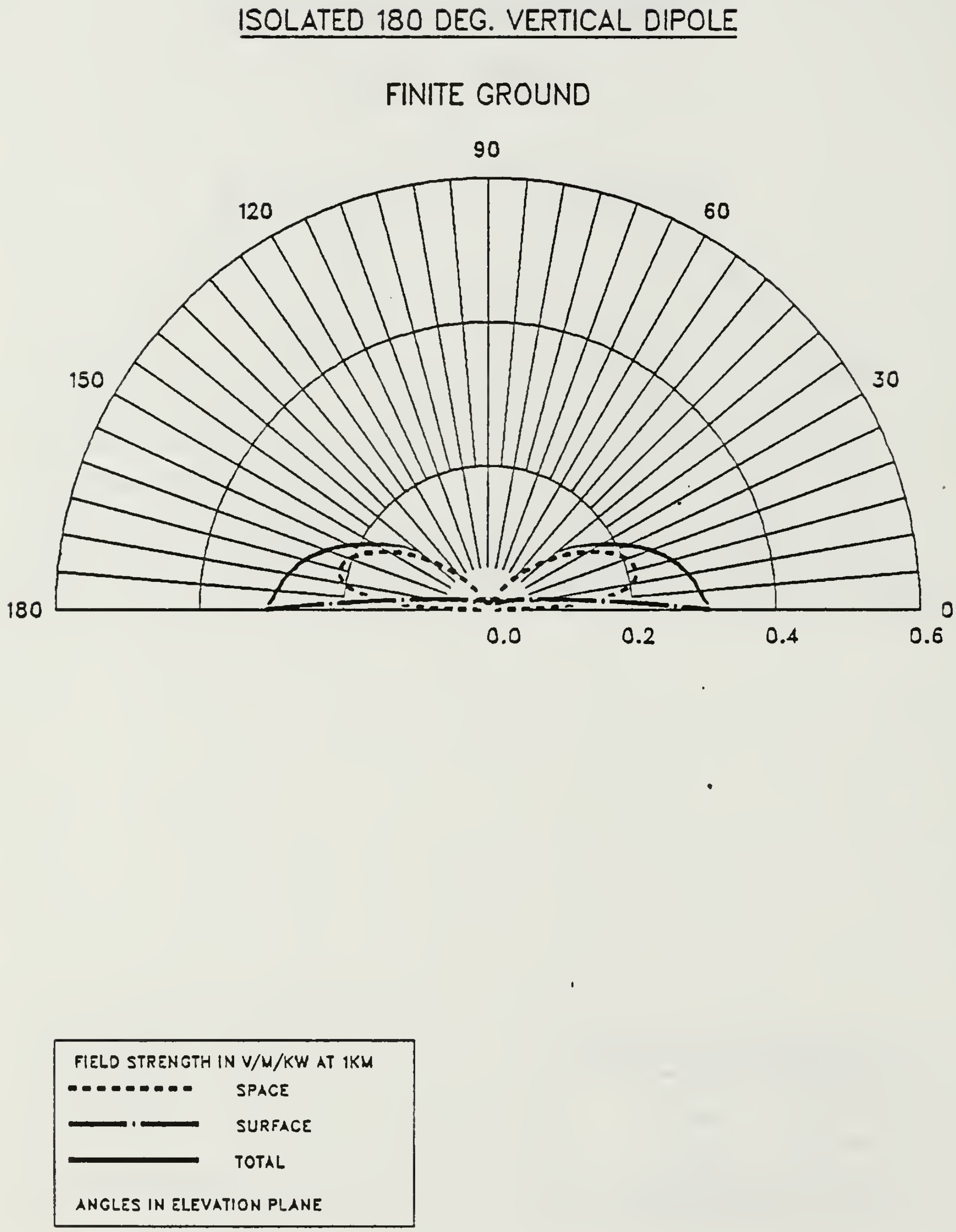


Figure A.3 Radiation Pattern - 180 Deg. Dipole over Finite Ground.

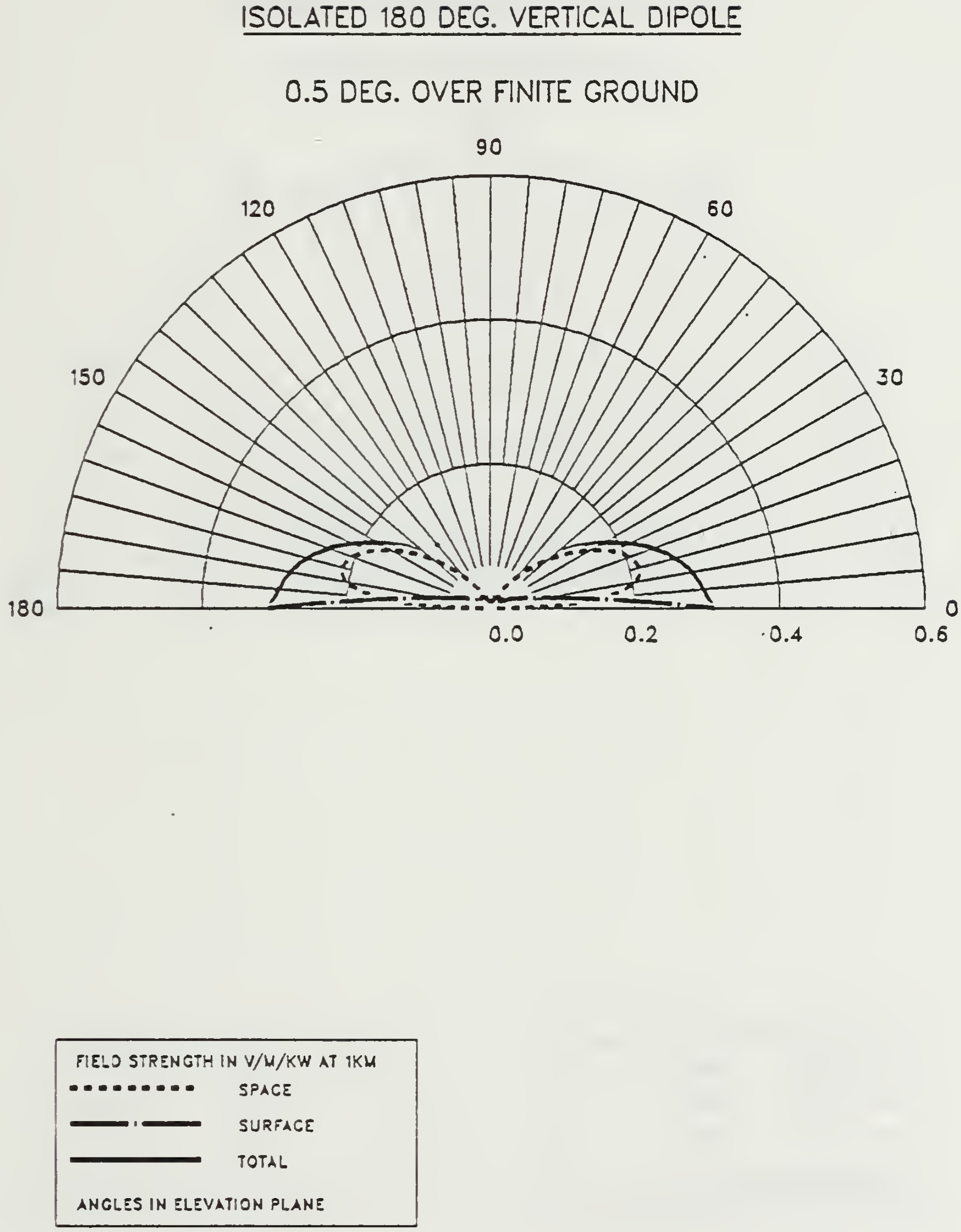


Figure A.4 Radiation Pattern - 180 Deg. Dipole 0.5 Deg. over Finite Ground.

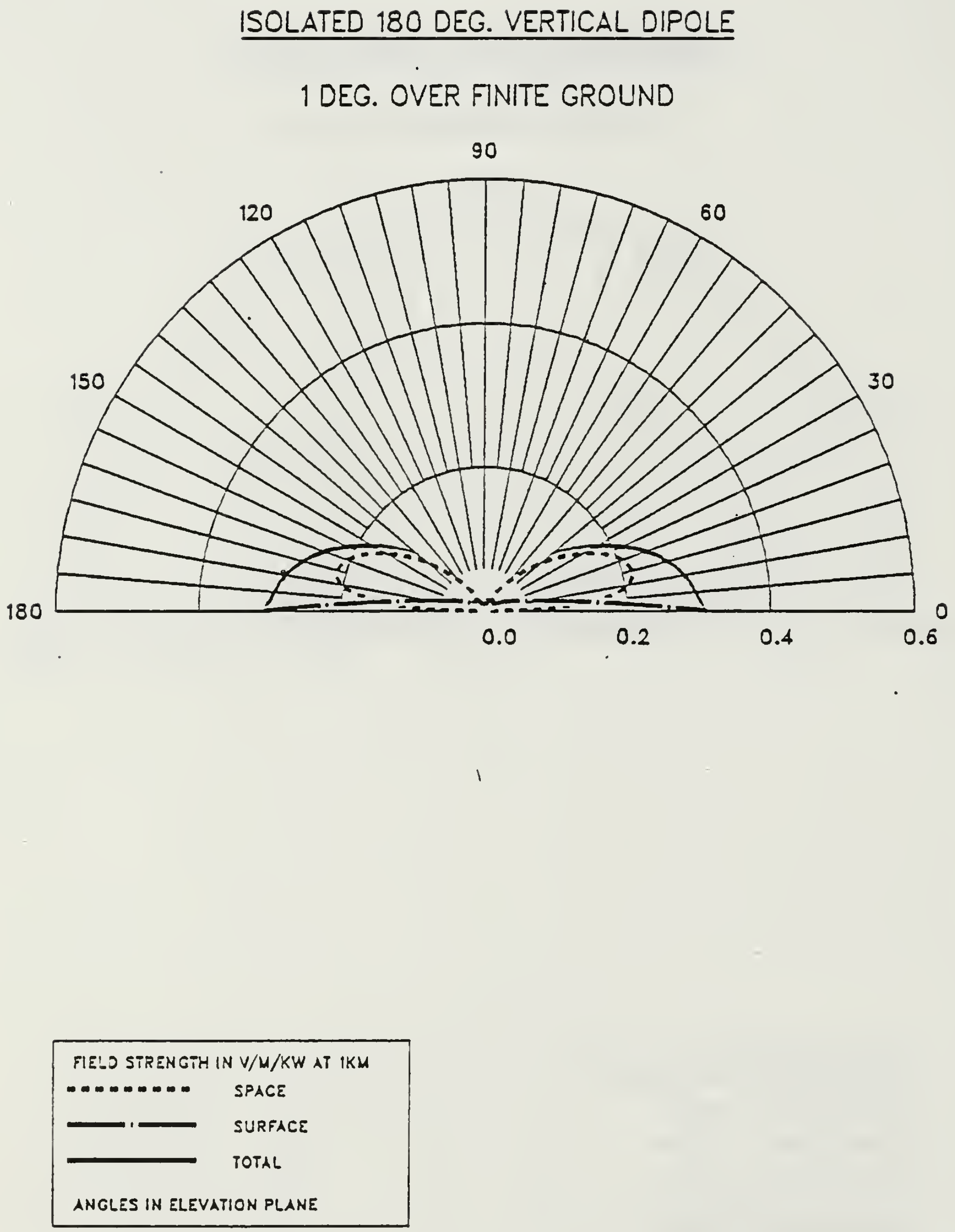


Figure A.5 Radiation Pattern - 180 Deg. Dipole 1 Deg. over Finite Ground.

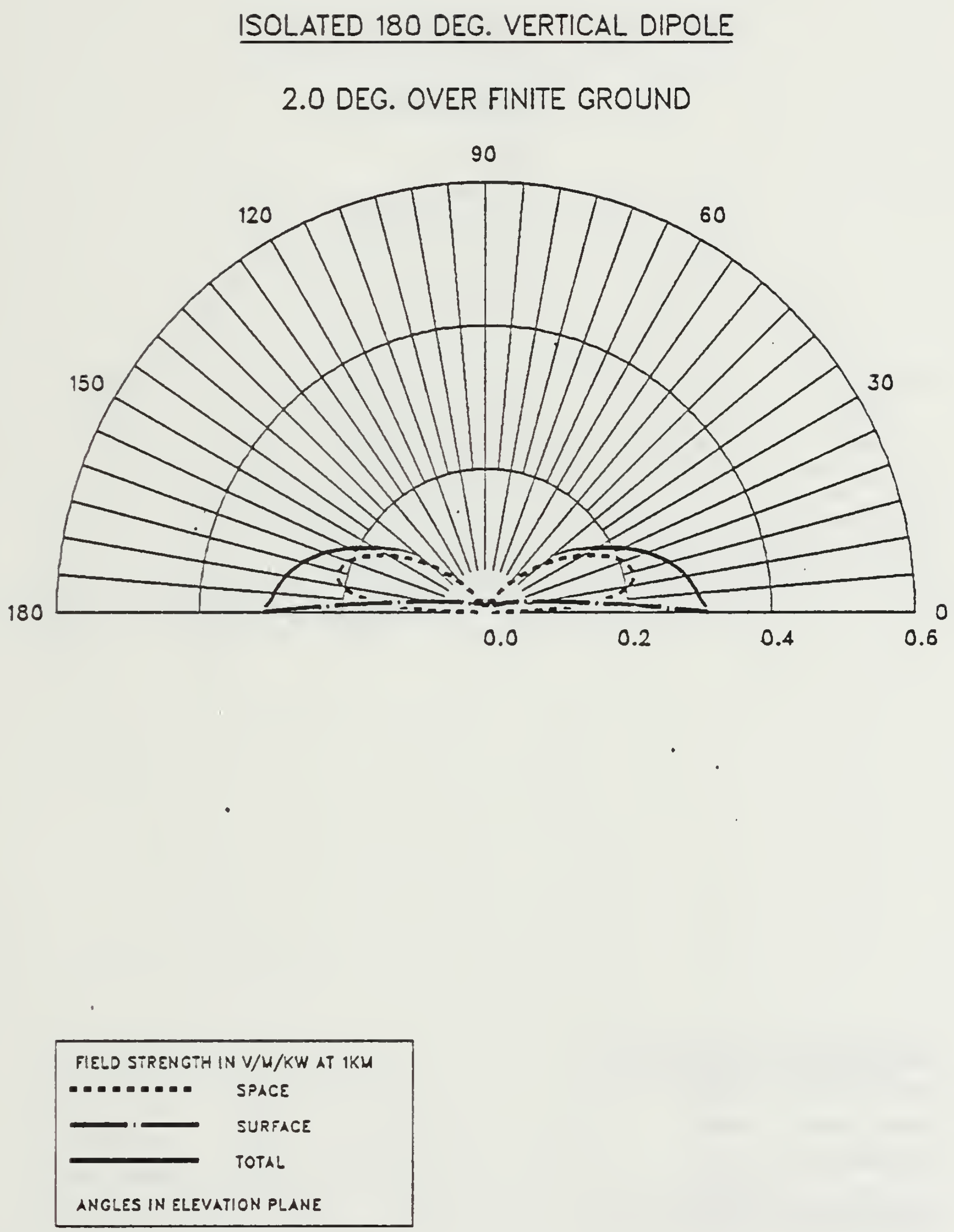


Figure A.6 Radiation Pattern - 180 Deg. Dipole 2 Deg. over Finite Ground.

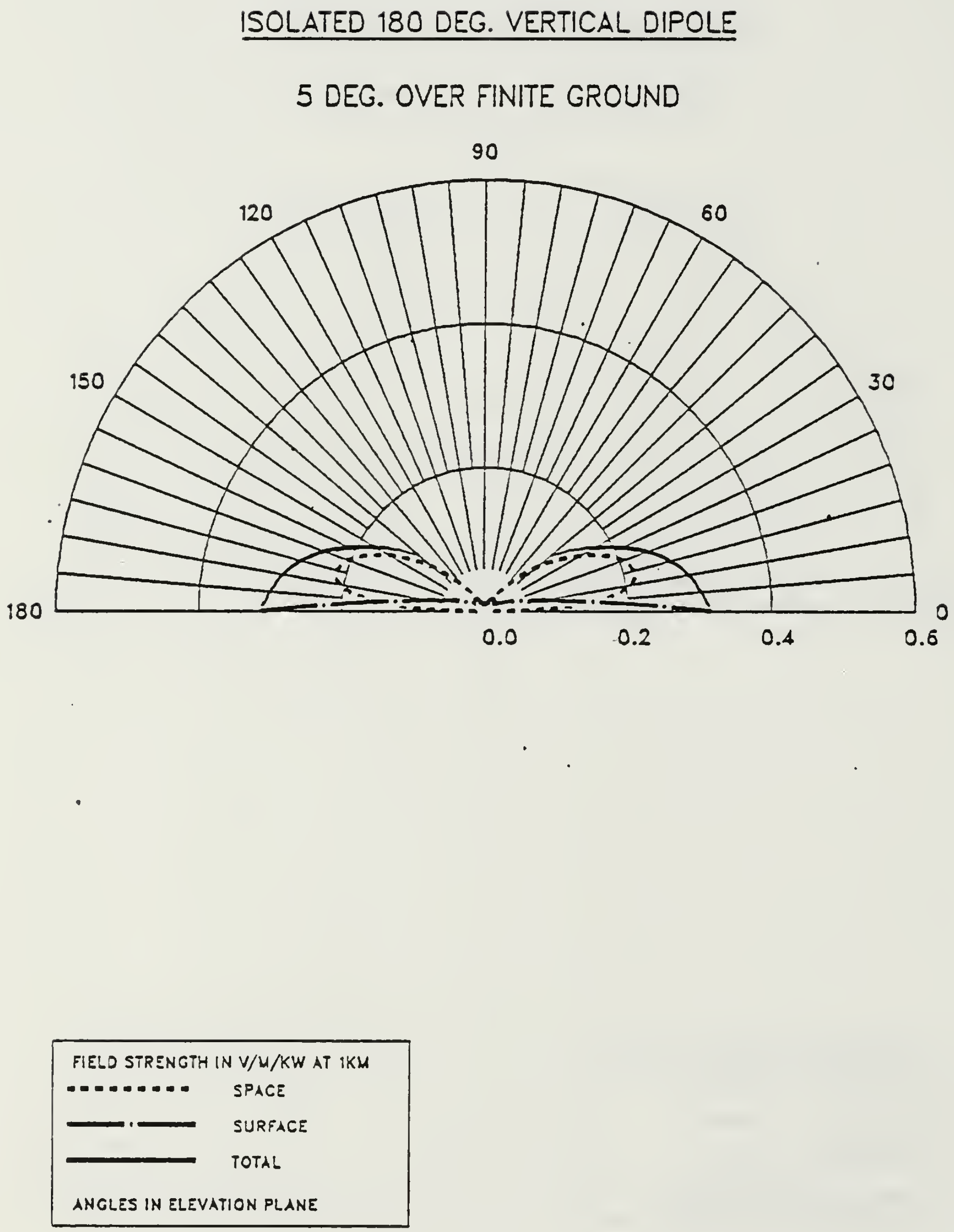


Figure A.7 Radiation Pattern - 180 Deg. Dipole 5 Deg. over Finite Ground.

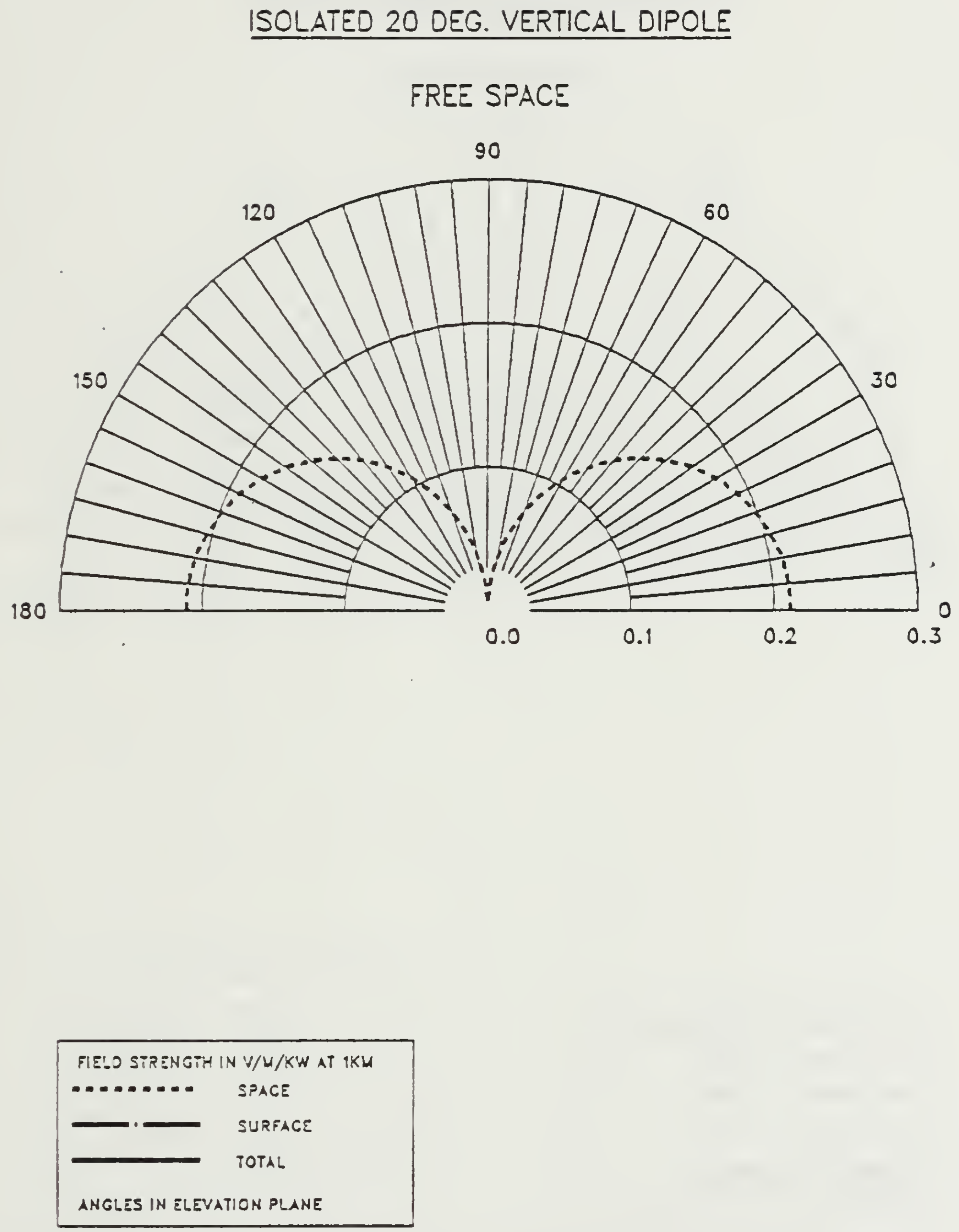


Figure A.8 Radiation Pattern - 20 Deg. Dipole in Free Space.

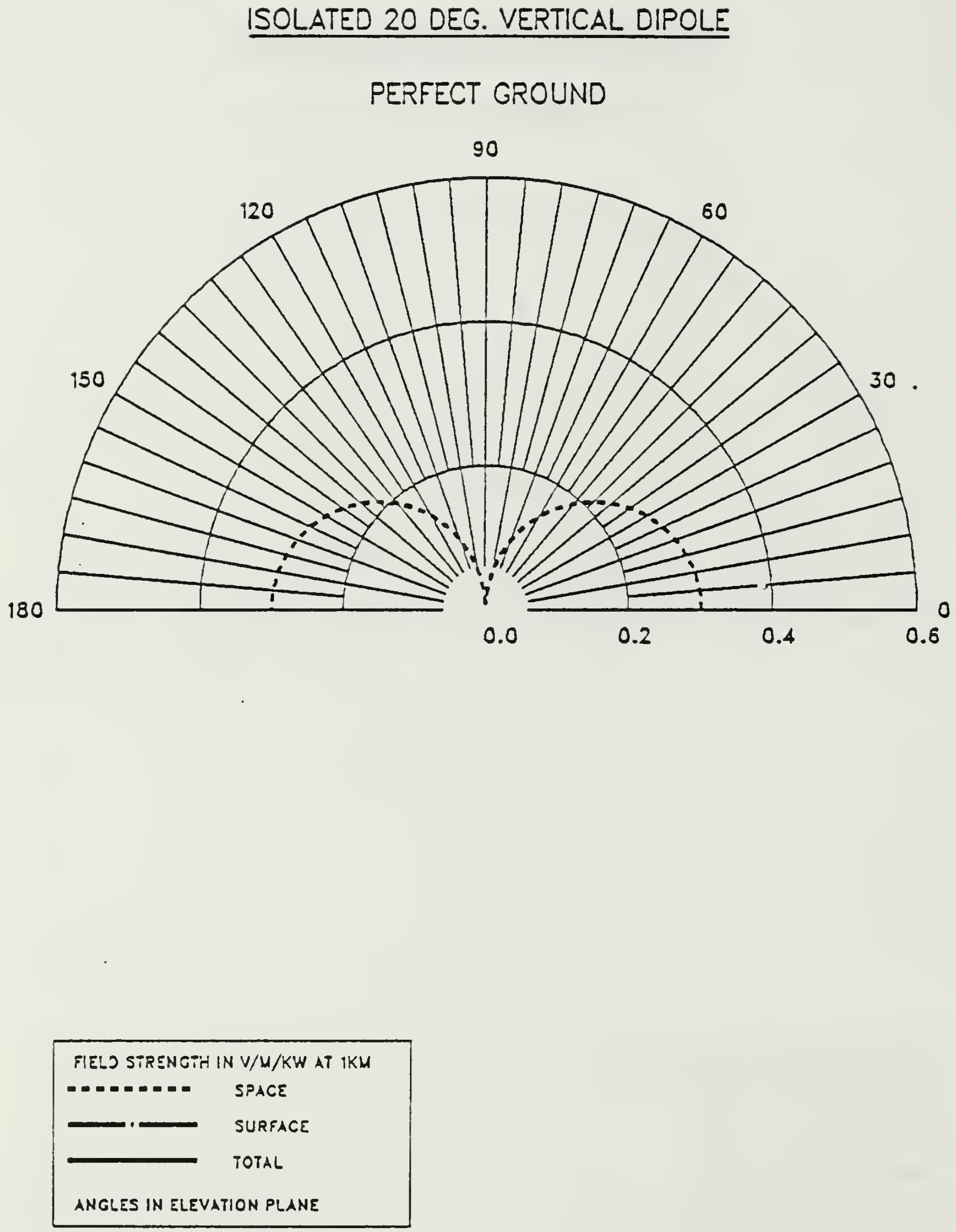


Figure A.9 Radiation Pattern - 20 Deg. Dipole over Perfect Ground.

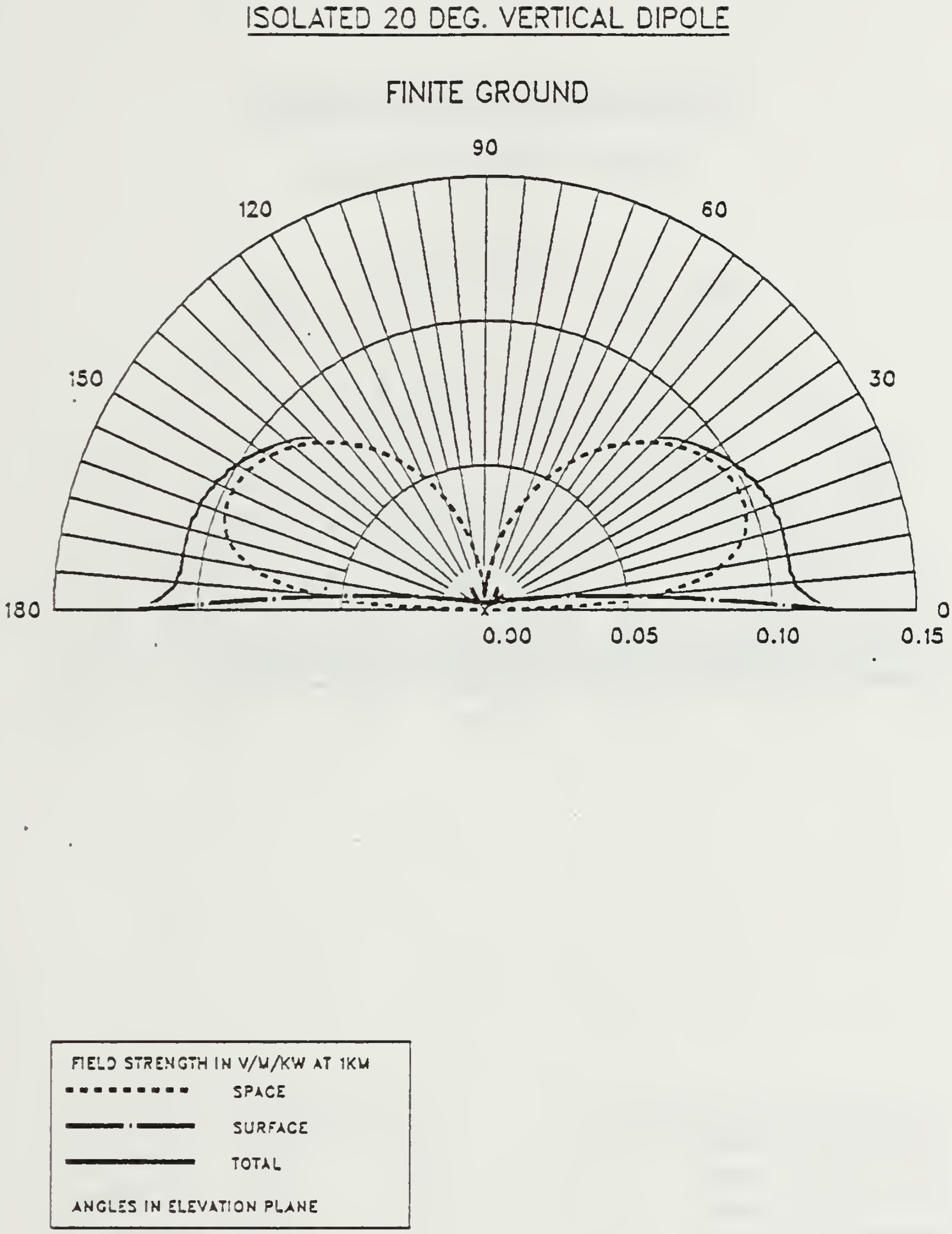


Figure A.10 Radiation Pattern - 20 Deg. Dipole over Finite Ground.

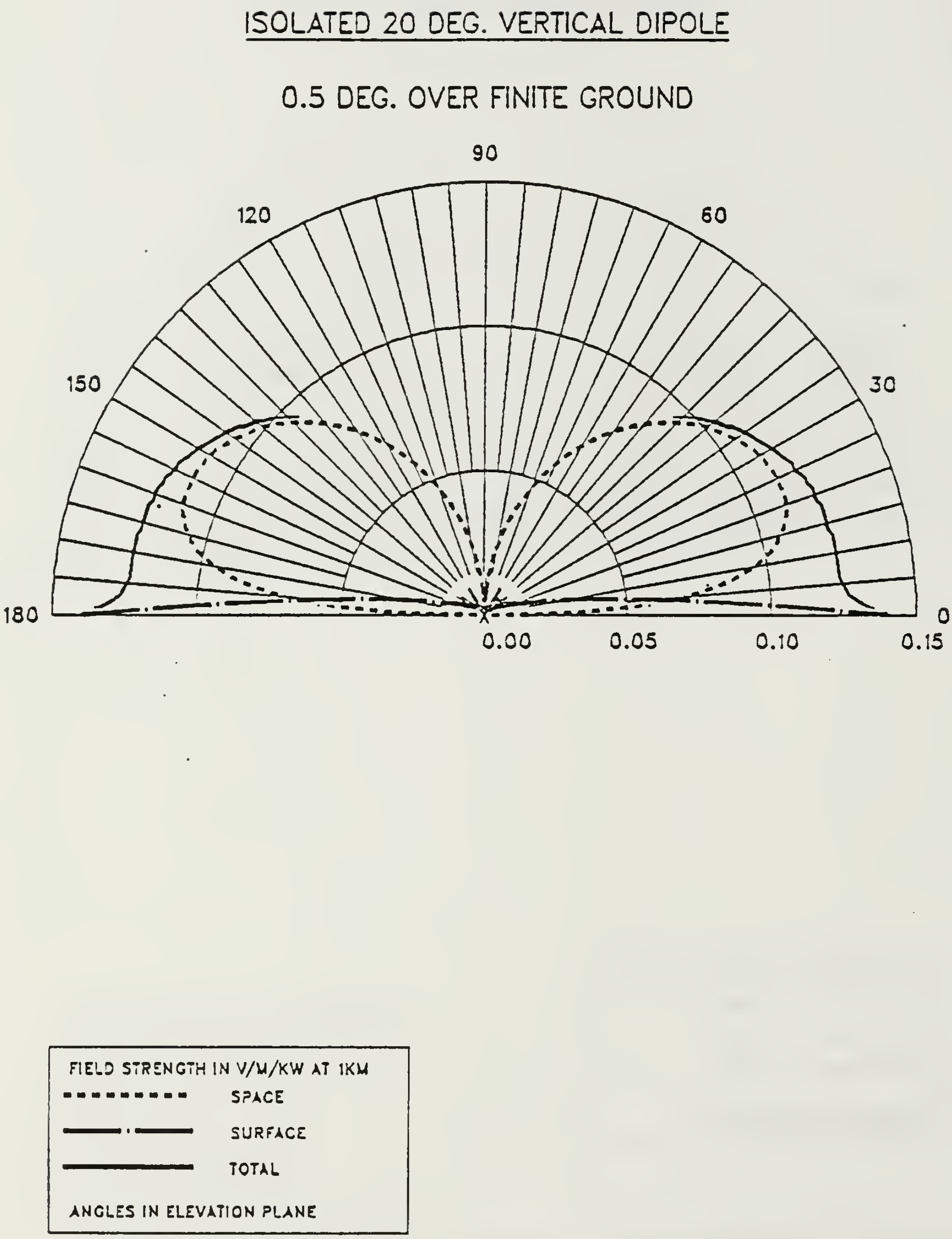


Figure A.11 Radiation Pattern - 20 Deg. Dipole 0.5 Deg. over Finite Ground.

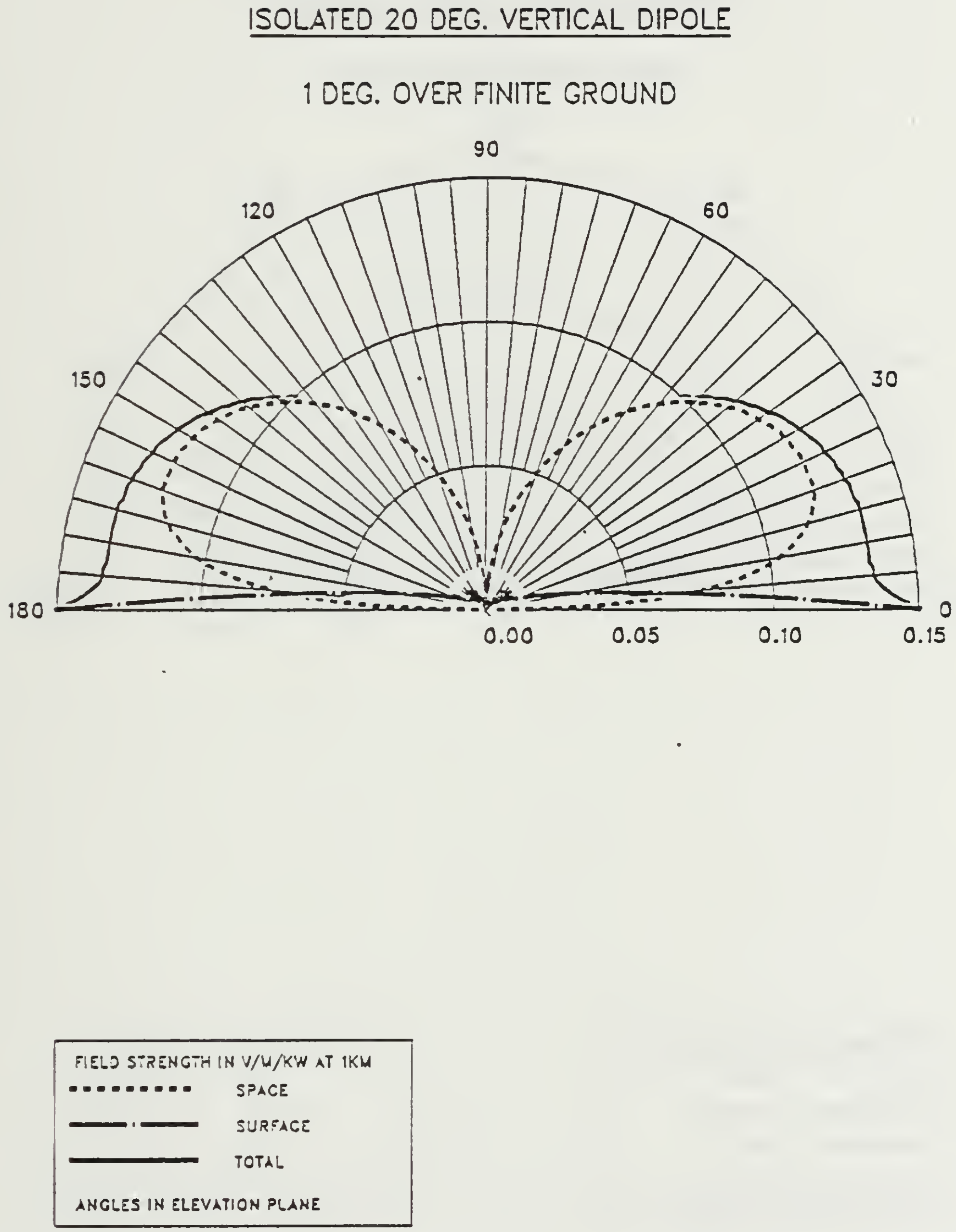


Figure A.12 Radiation Pattern - 20 Deg. Dipole 1 Deg. over Finite Ground.

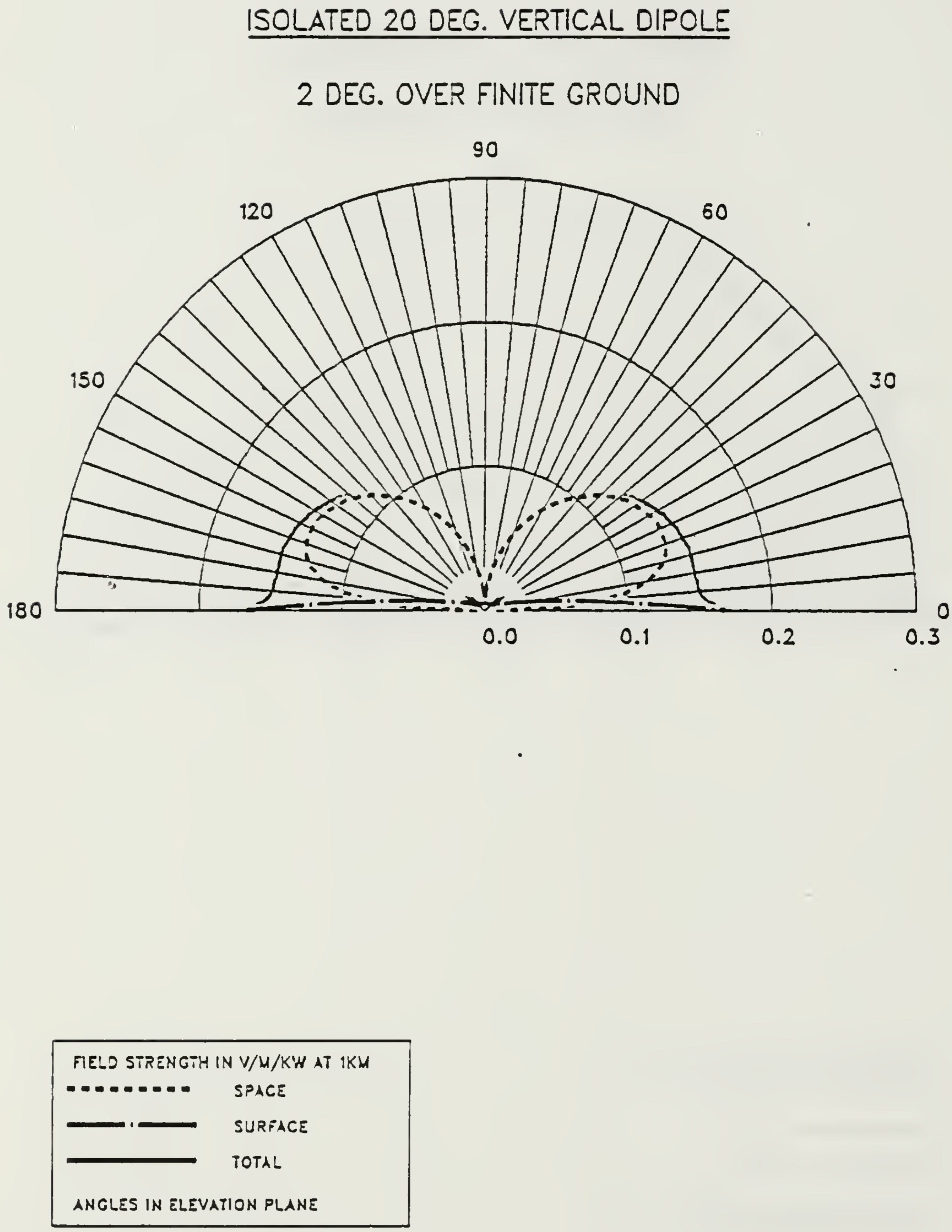


Figure A.13 Radiation Pattern - 20 Deg. Dipole 2 Deg. over Finite Ground.

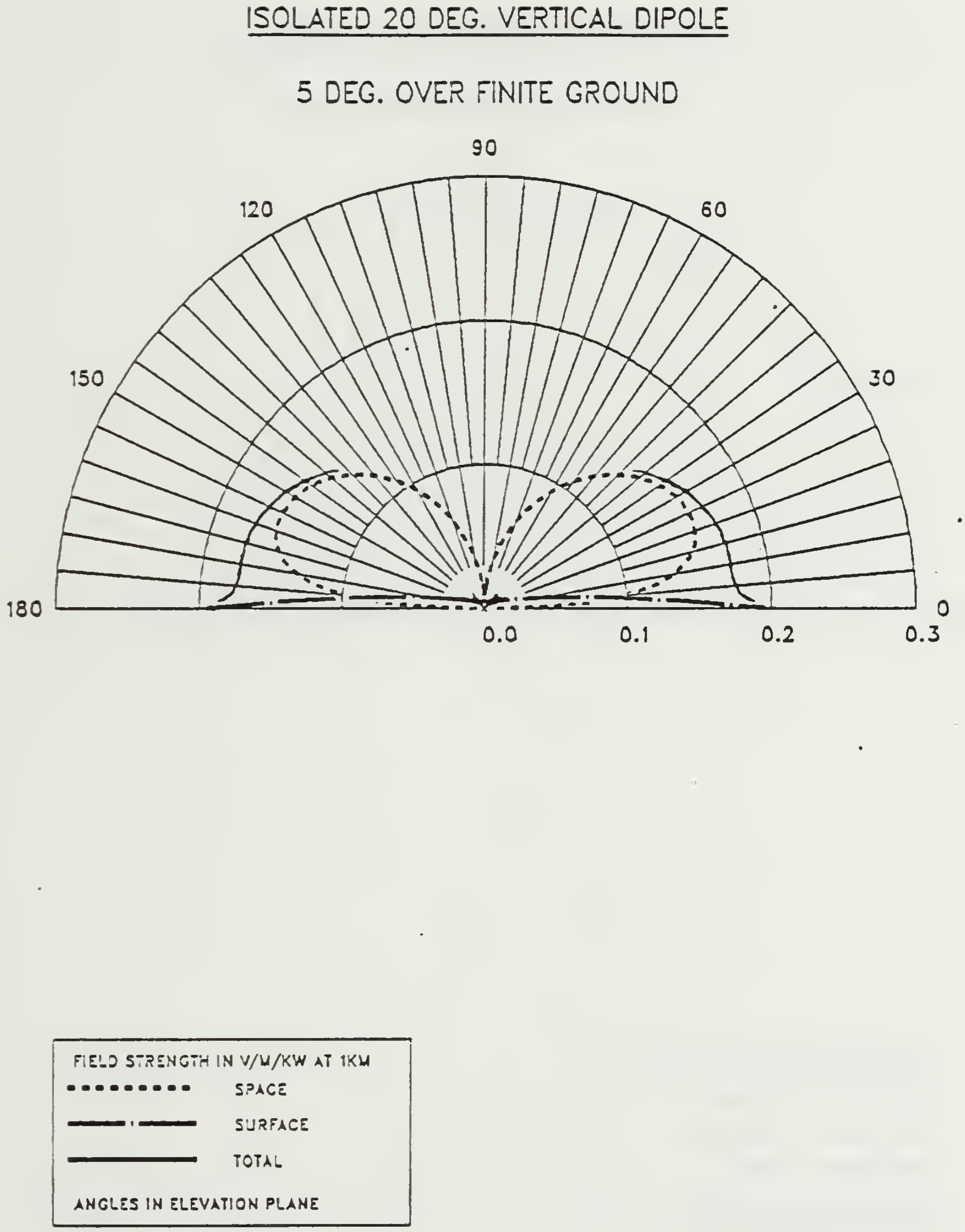


Figure A.14 Radiation Pattern - 20 Deg. Dipole 5 Deg. over Finite Ground.

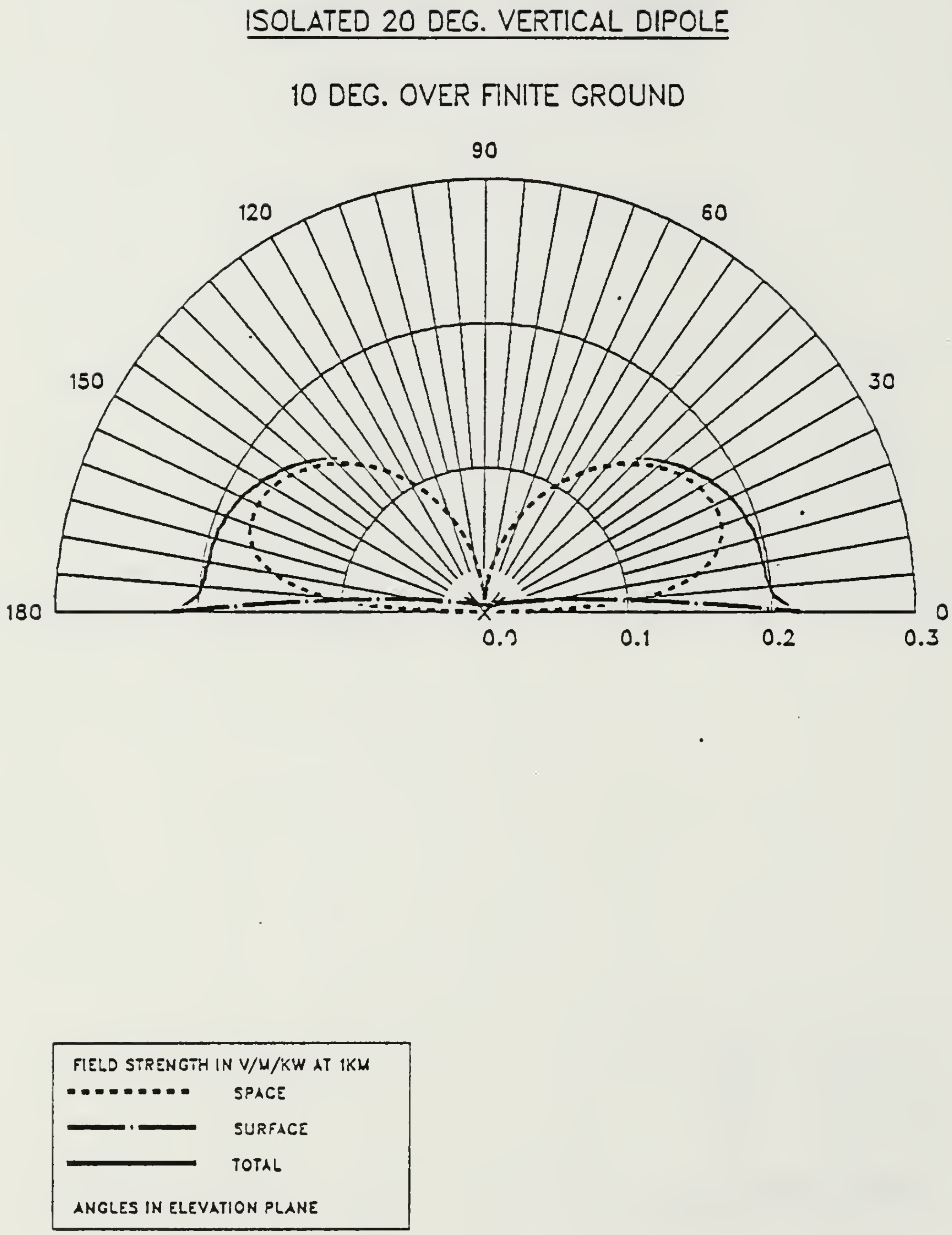


Figure A.15 Radiation Pattern - 20 Deg. Dipole 10 Deg. over Finite Ground.

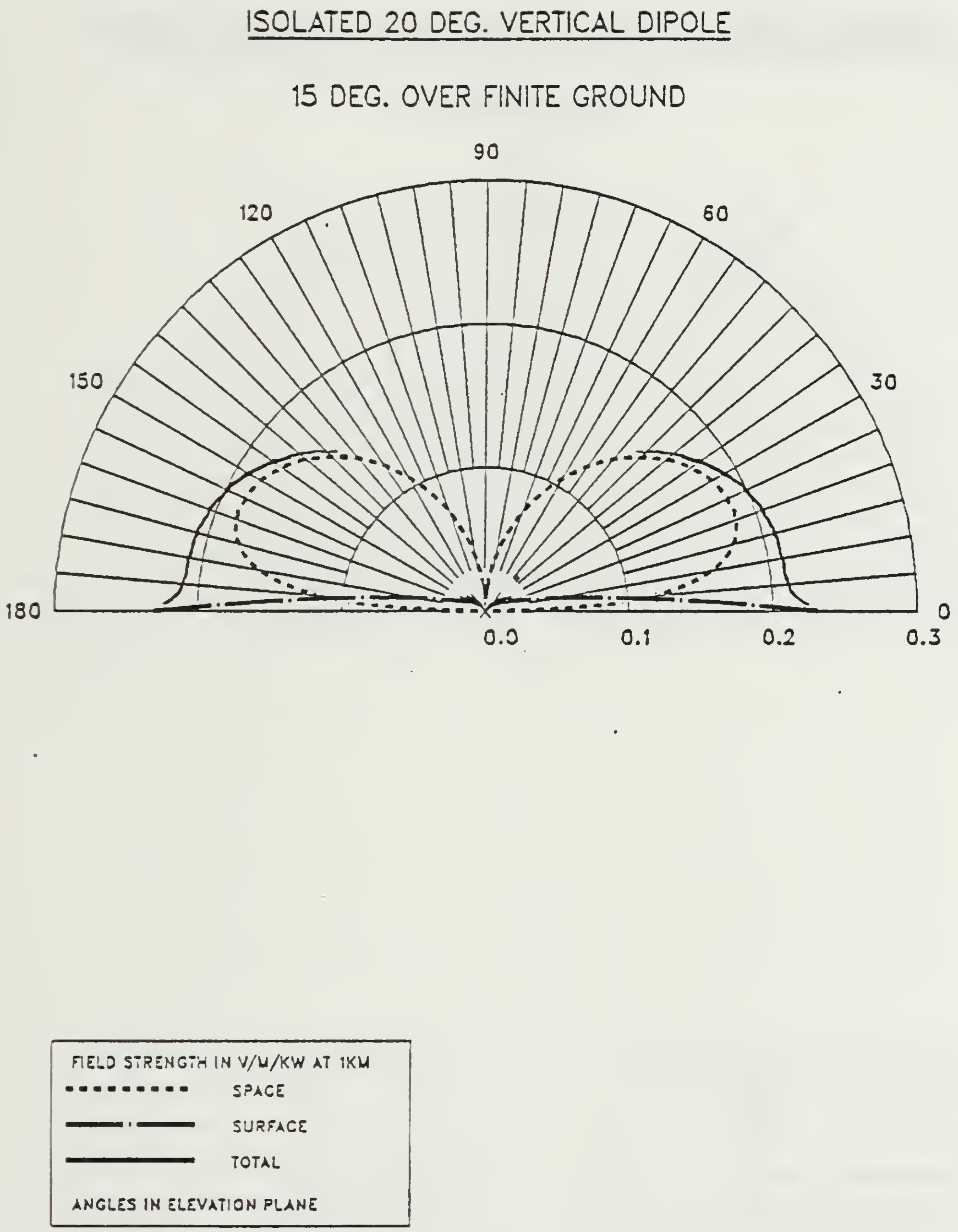


Figure A.16 Radiation Pattern - 20 Deg. Dipole 15 Deg. over Finite Ground.

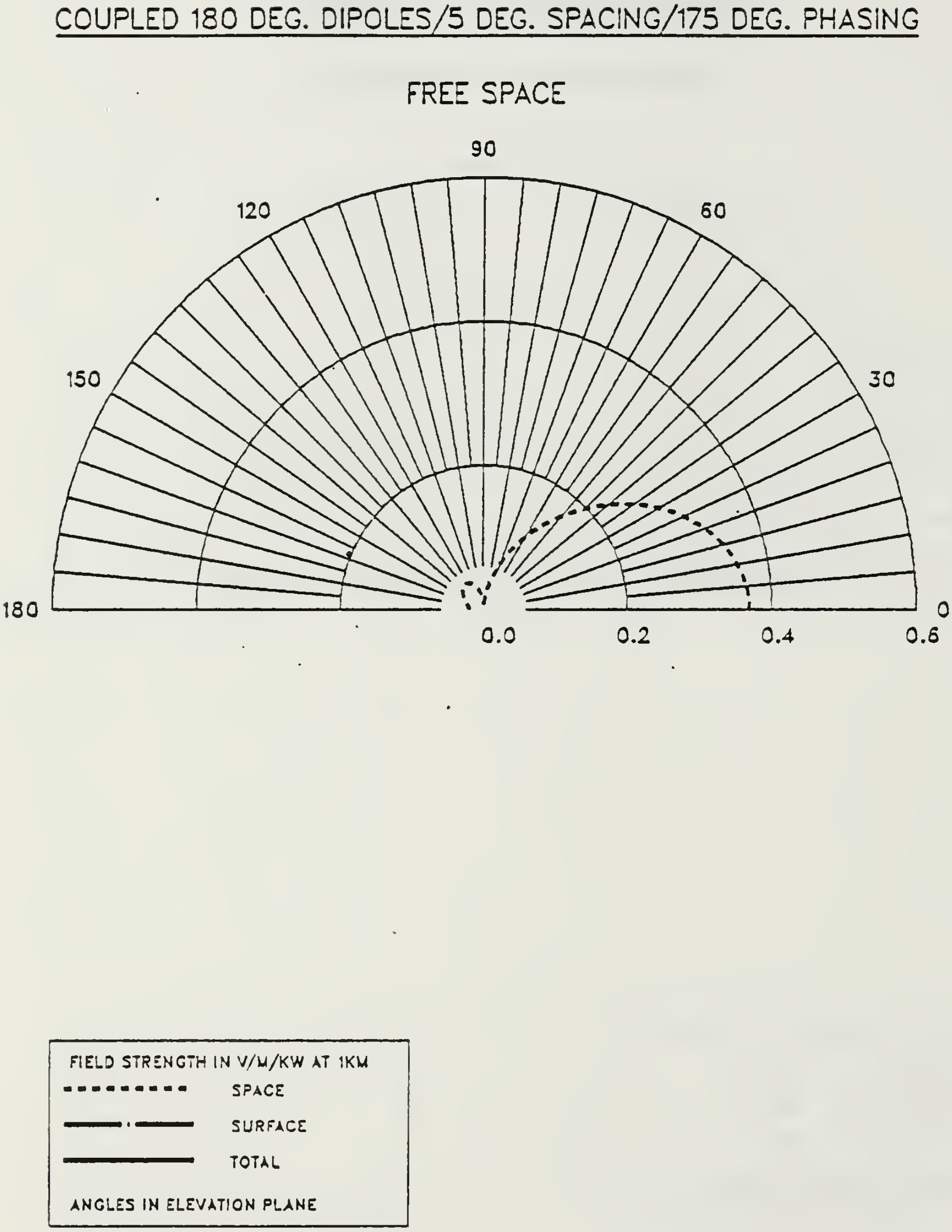


Figure A.17 Radiation Pattern - 180 Deg. Coupled Dipoles in Free Space.

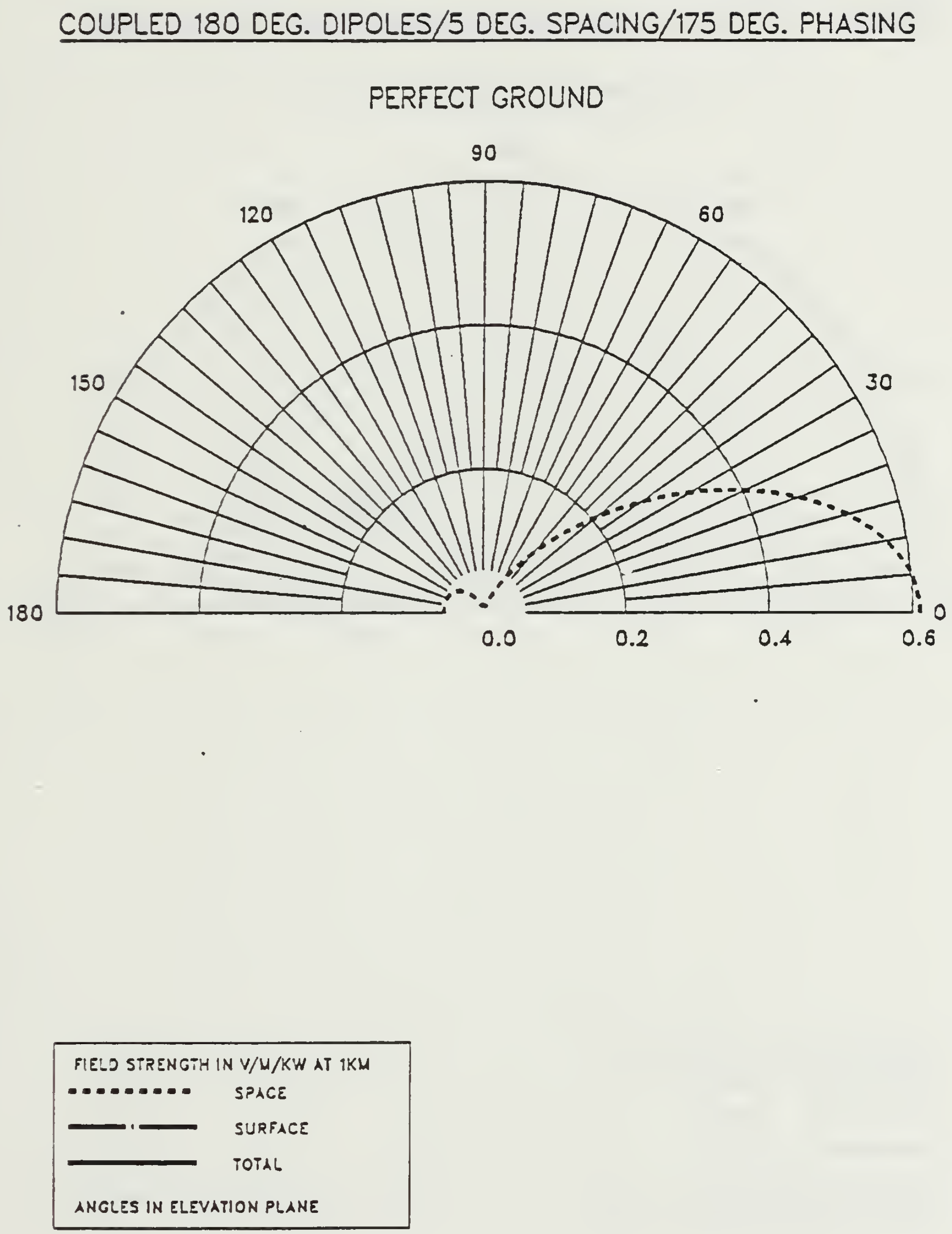


Figure A.18 Radiation Pattern - 180 Deg. Coupled Dipoles over Perfect Ground.

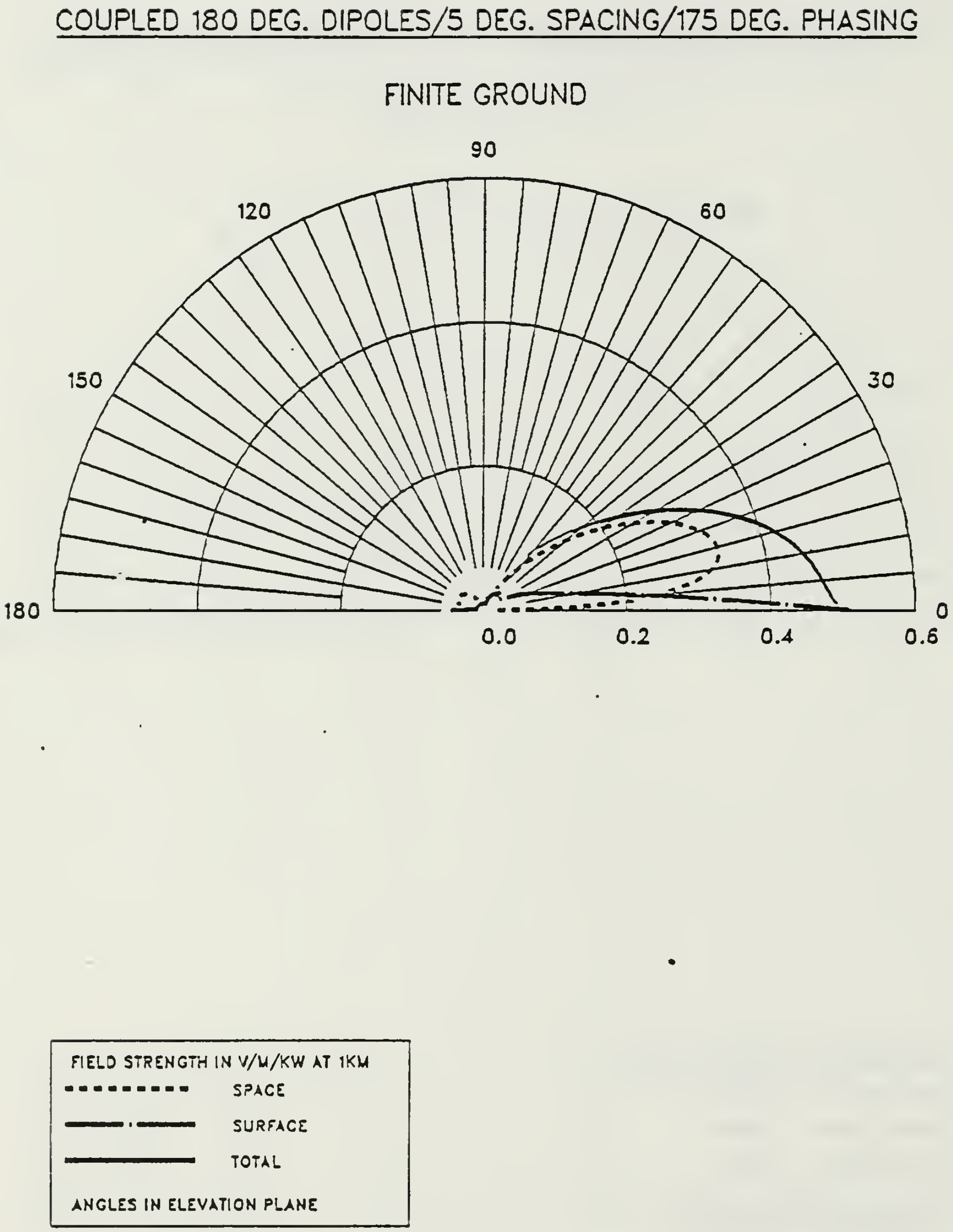


Figure A.19 Radiation Pattern - 180 Deg. Coupled Dipoles over Finite Ground.

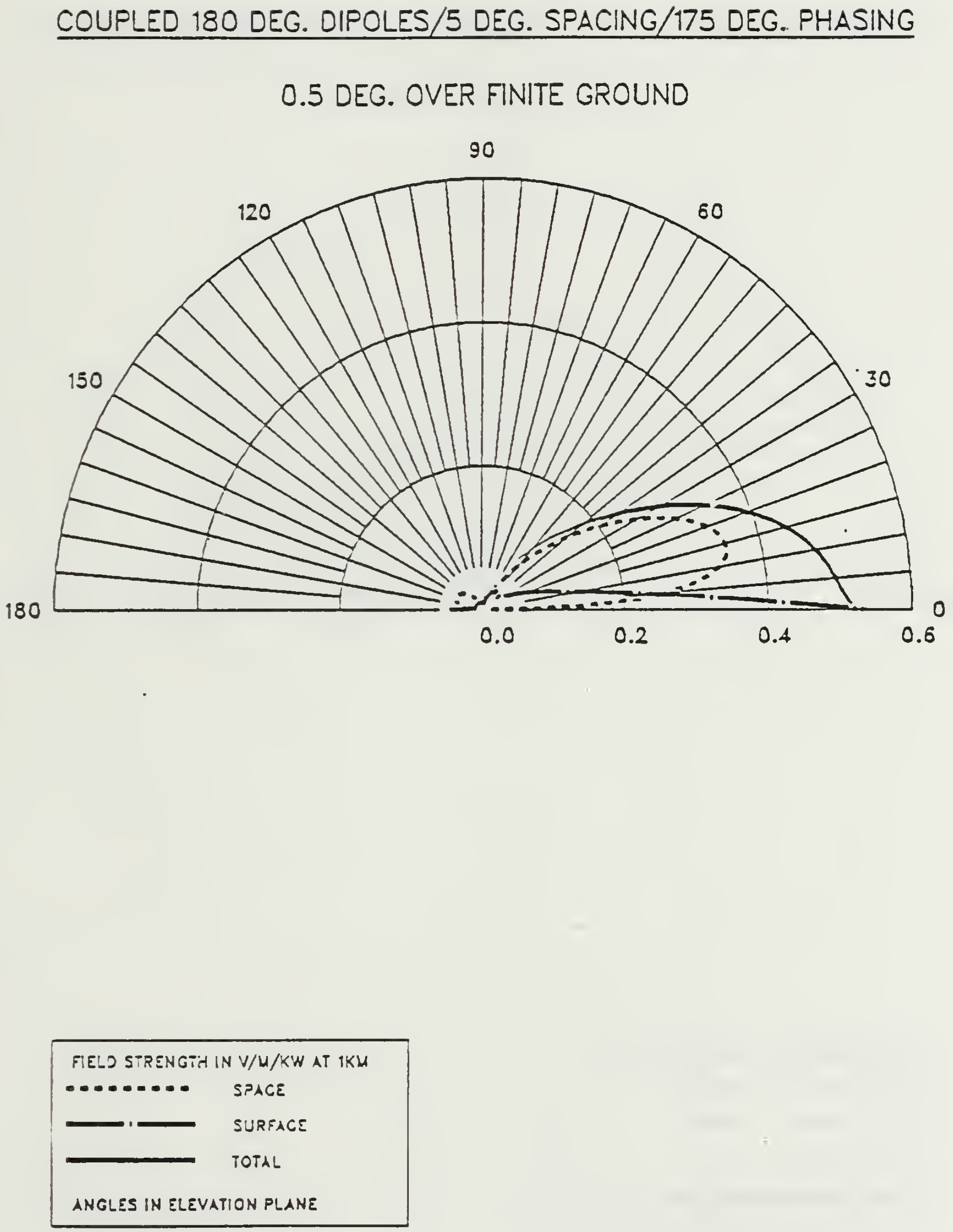


Figure A.20 Radiation Pattern - 180 Deg. Coupled Dipoles 0.5 Deg. over Finite Ground.

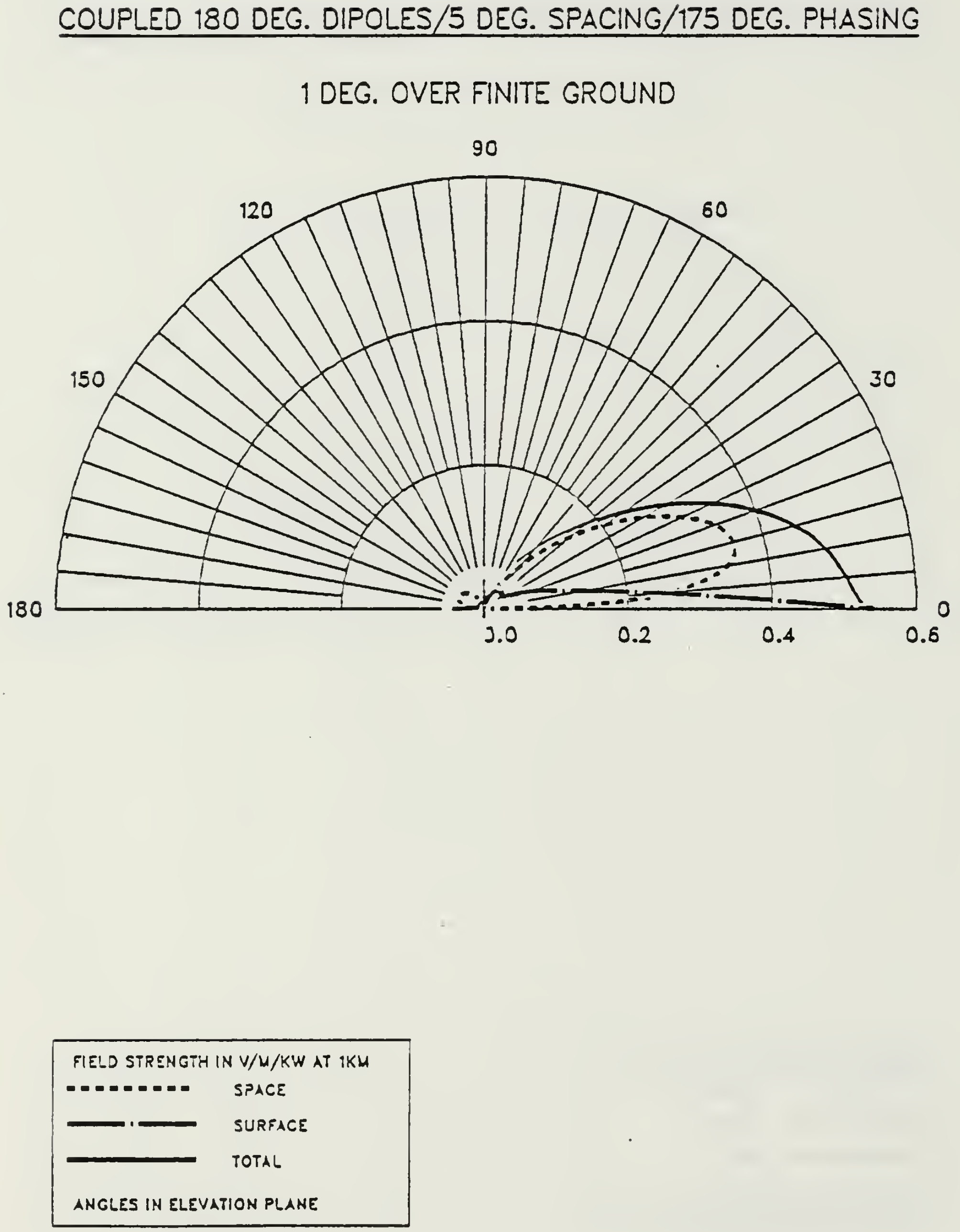


Figure A.21 Radiation Pattern - 180 Deg. Coupled Dipoles 1 Deg. over Finite Ground.

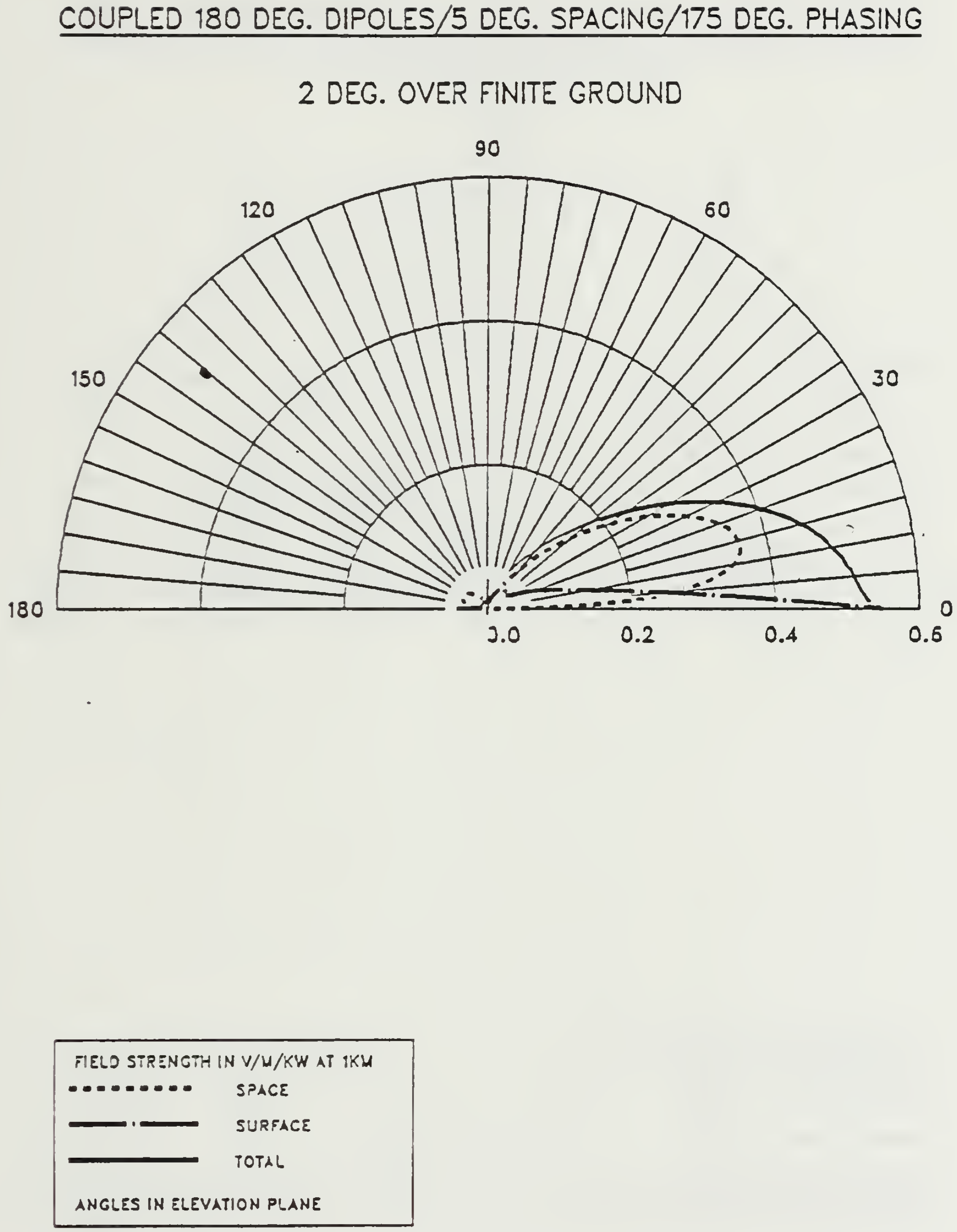


Figure A.22 Radiation Pattern - 180 Deg. Coupled Dipoles 2 Deg. over Finite Ground.

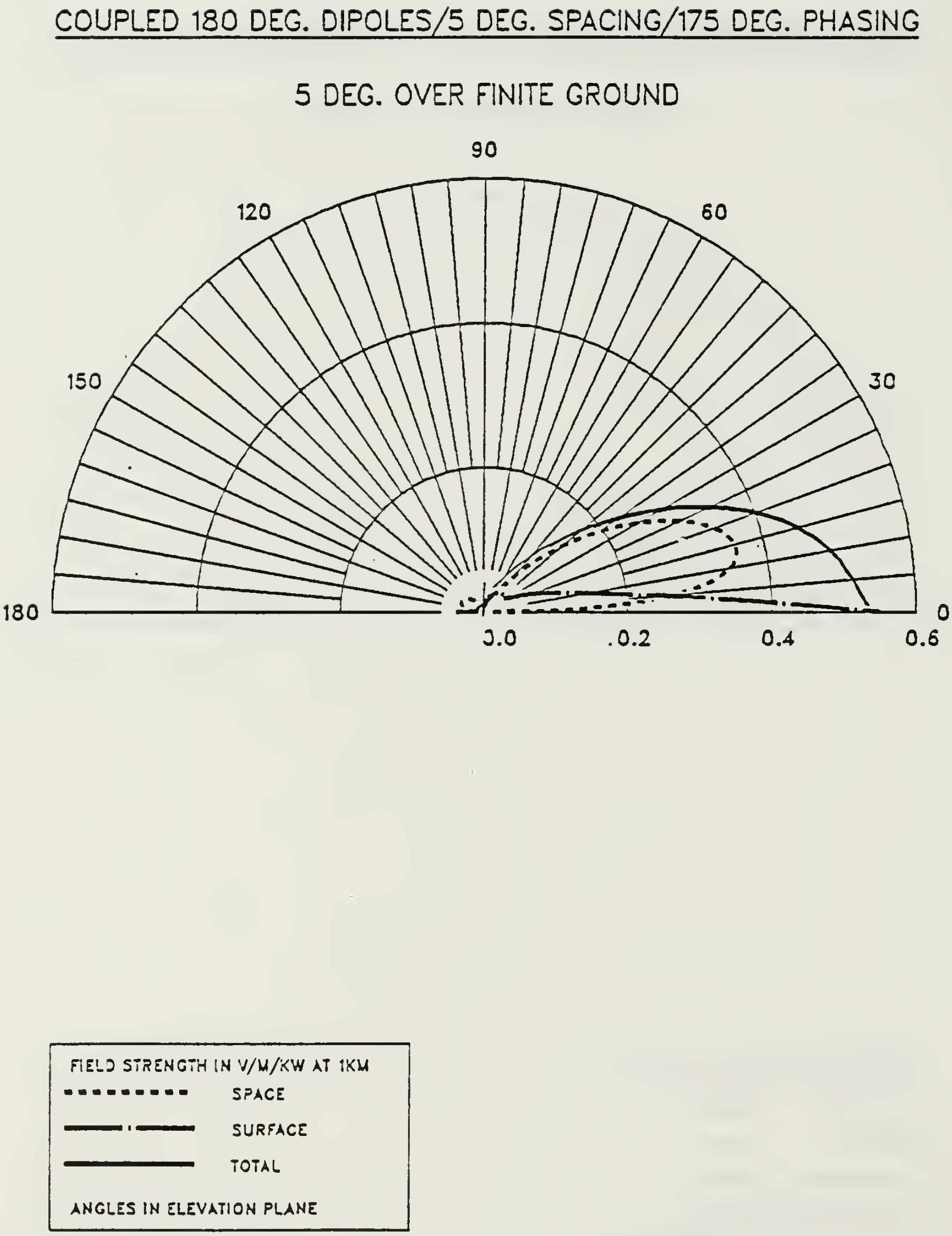


Figure A.23 Radiation Pattern - 180 Deg. Coupled Dipoles 5 Deg. over Finite Ground.

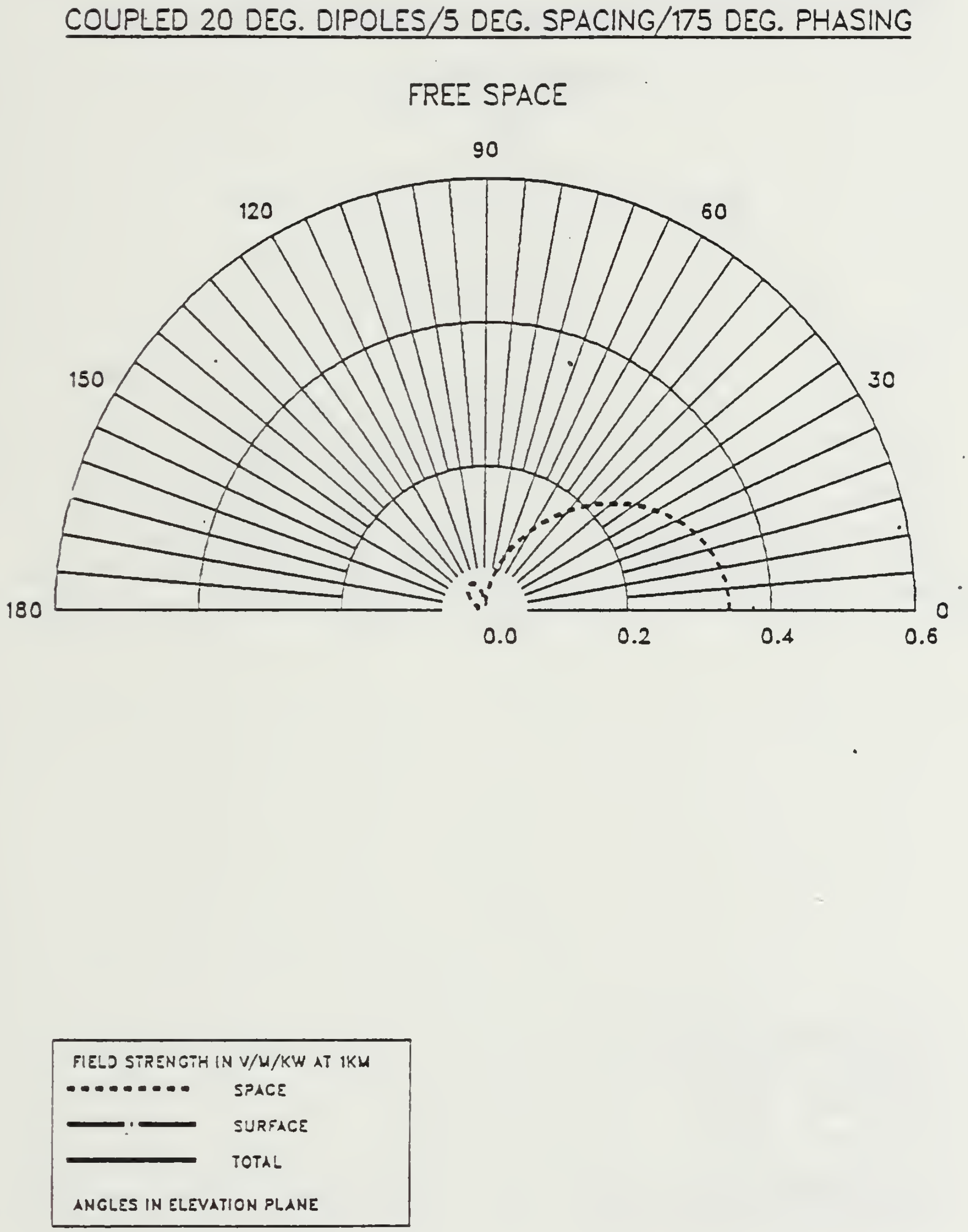


Figure A.24 Radiation Pattern - 20 Deg. Coupled Dipoles in Free Space.

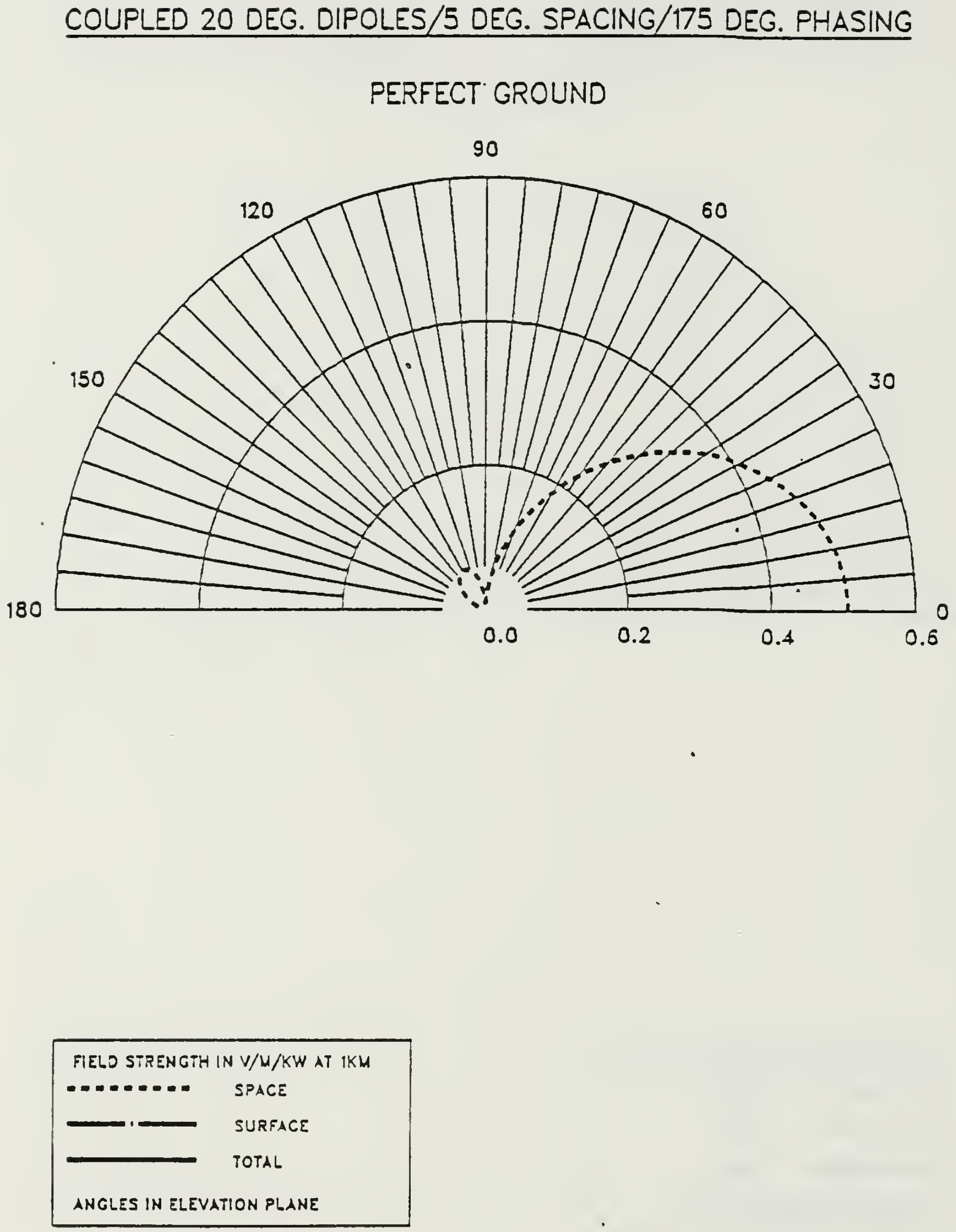


Figure A.25 Radiation Pattern - 20 Deg. Coupled Dipoles over Perfect Ground.

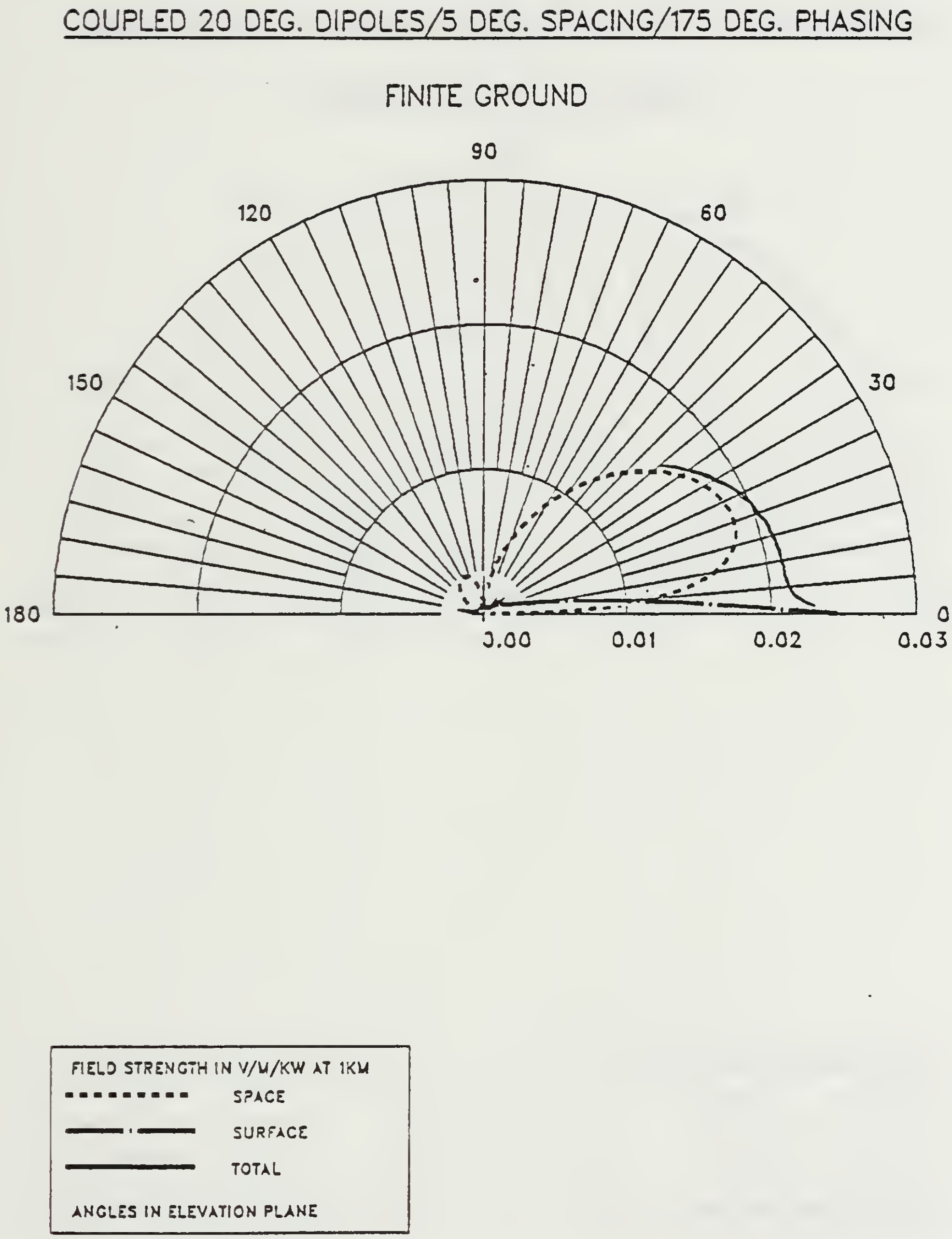


Figure A.26 Radiation Pattern - 20 Deg. Coupled Dipoles over Finite Ground.

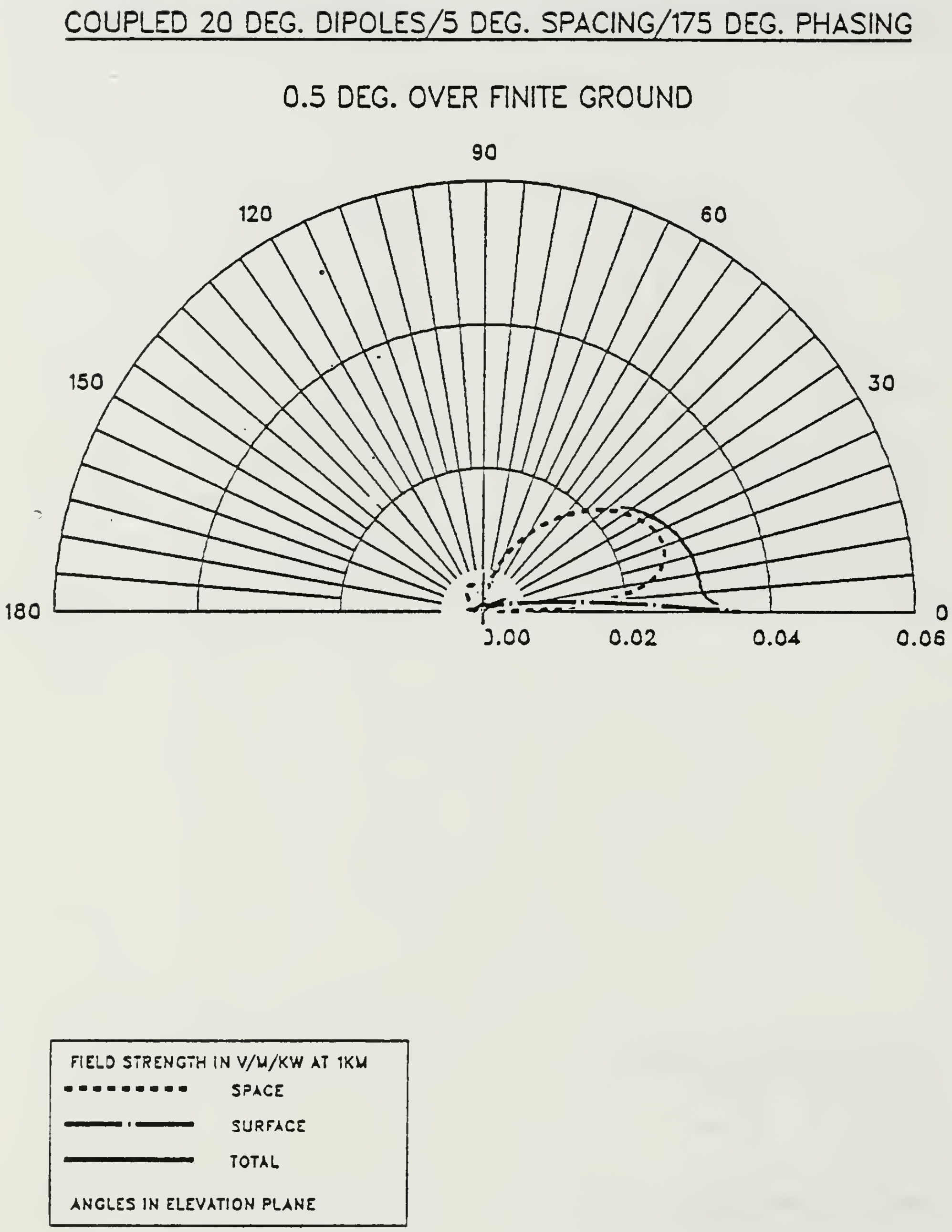


Figure A.27 Radiation Pattern - 20 Deg. Coupled Dipoles 0.5 Deg. over Finite Ground.

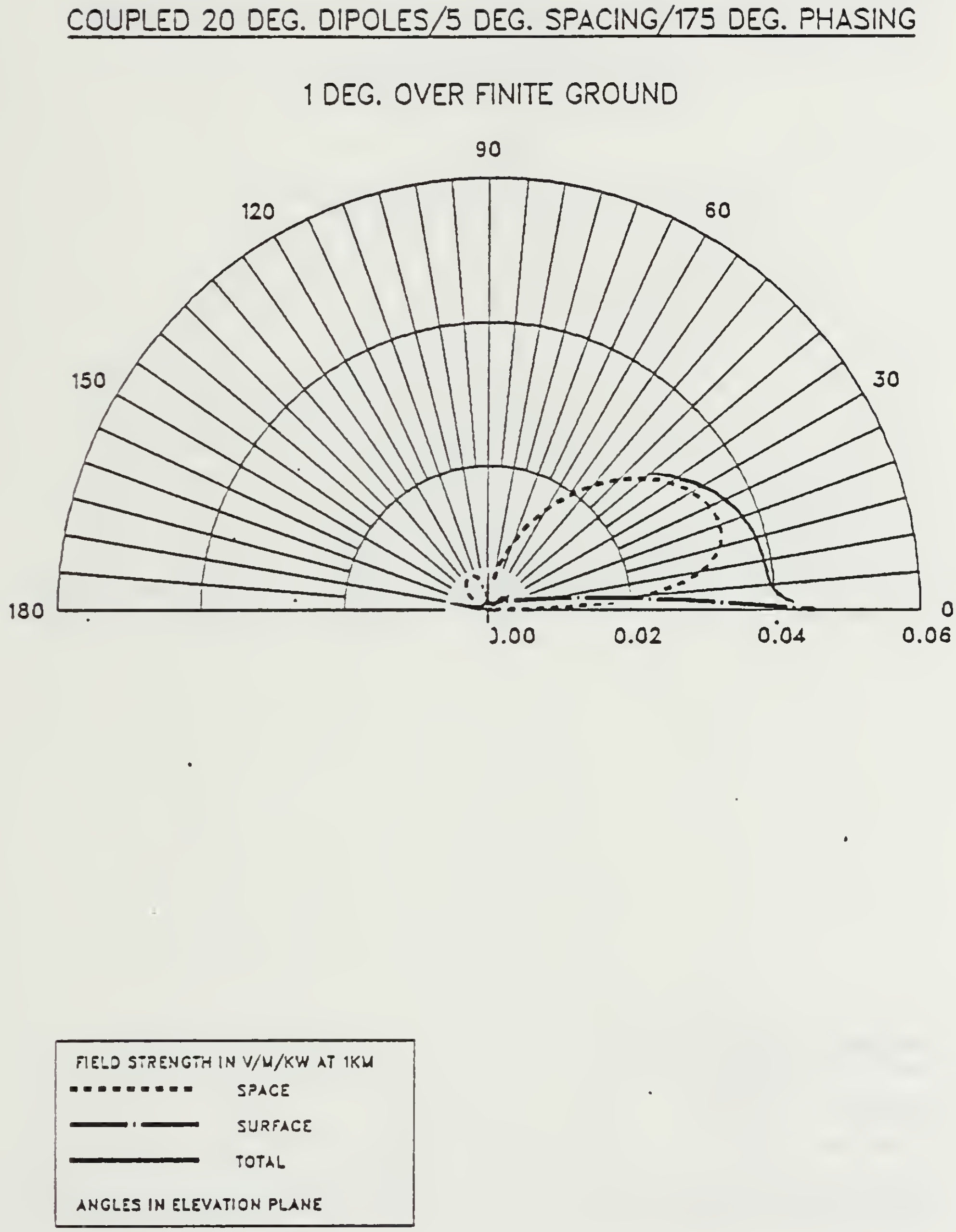


Figure A.28 Radiation Pattern - 20 Deg. Coupled Dipoles 1 Deg. over Finite Ground.

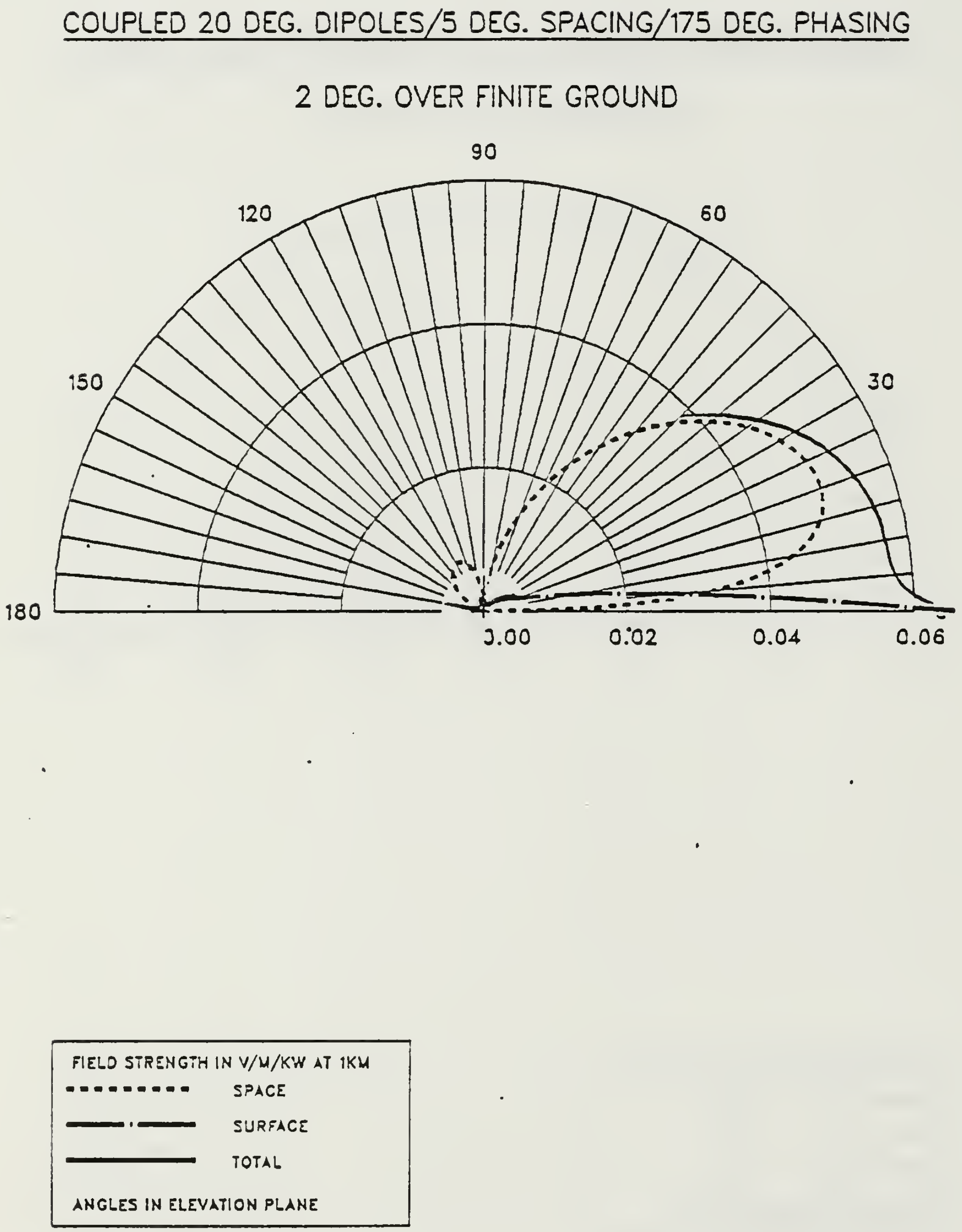


Figure A.29 Radiation Pattern - 20 Deg. Coupled Dipoles 2 Deg. over Finite Ground.

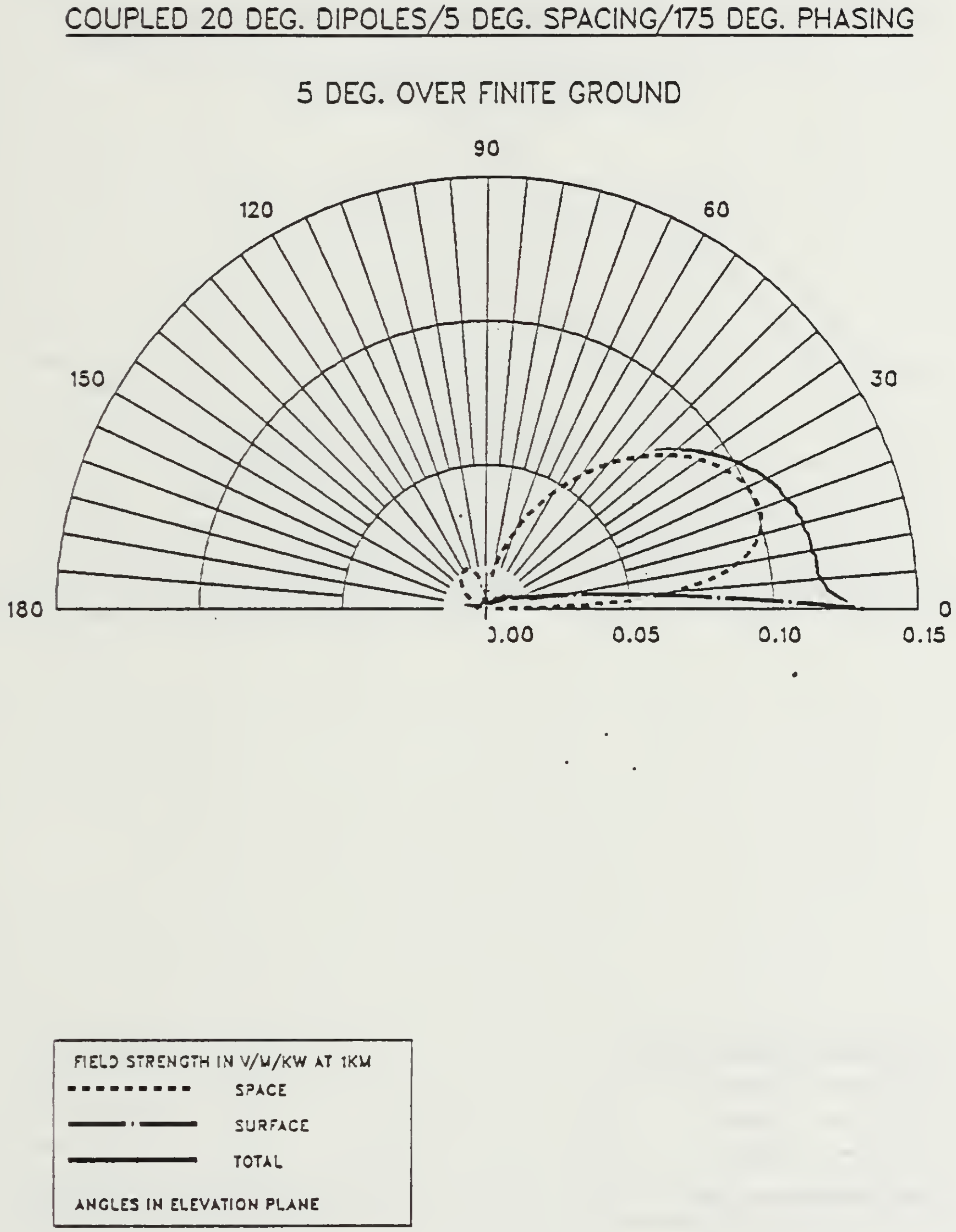


Figure A.30 Radiation Pattern - 20 Deg. Coupled Dipoles 5 Deg. over Finite Ground.

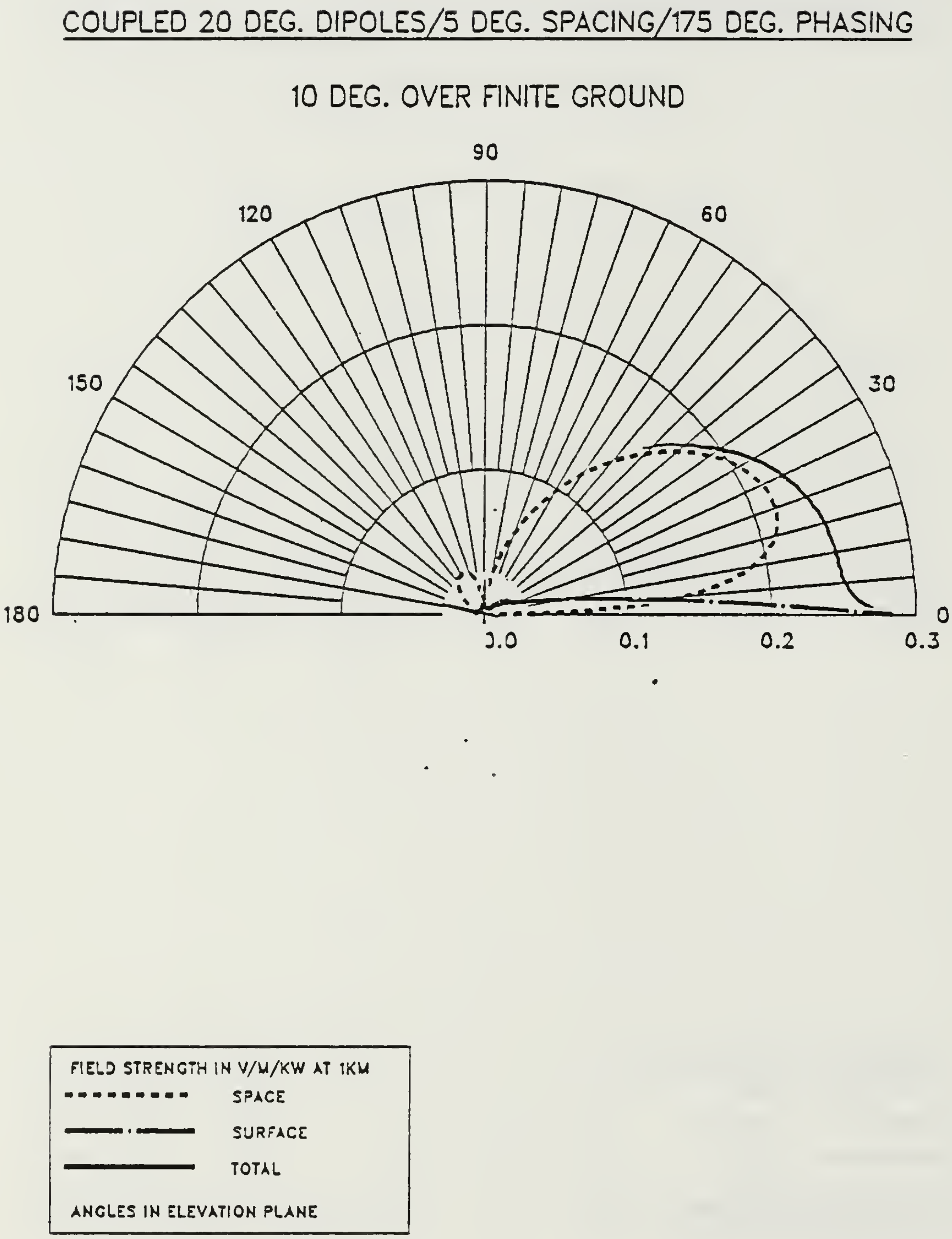


Figure A.31 Radiation Pattern - 20 Deg. Coupled Dipoles 10 Deg. over Finite Ground.

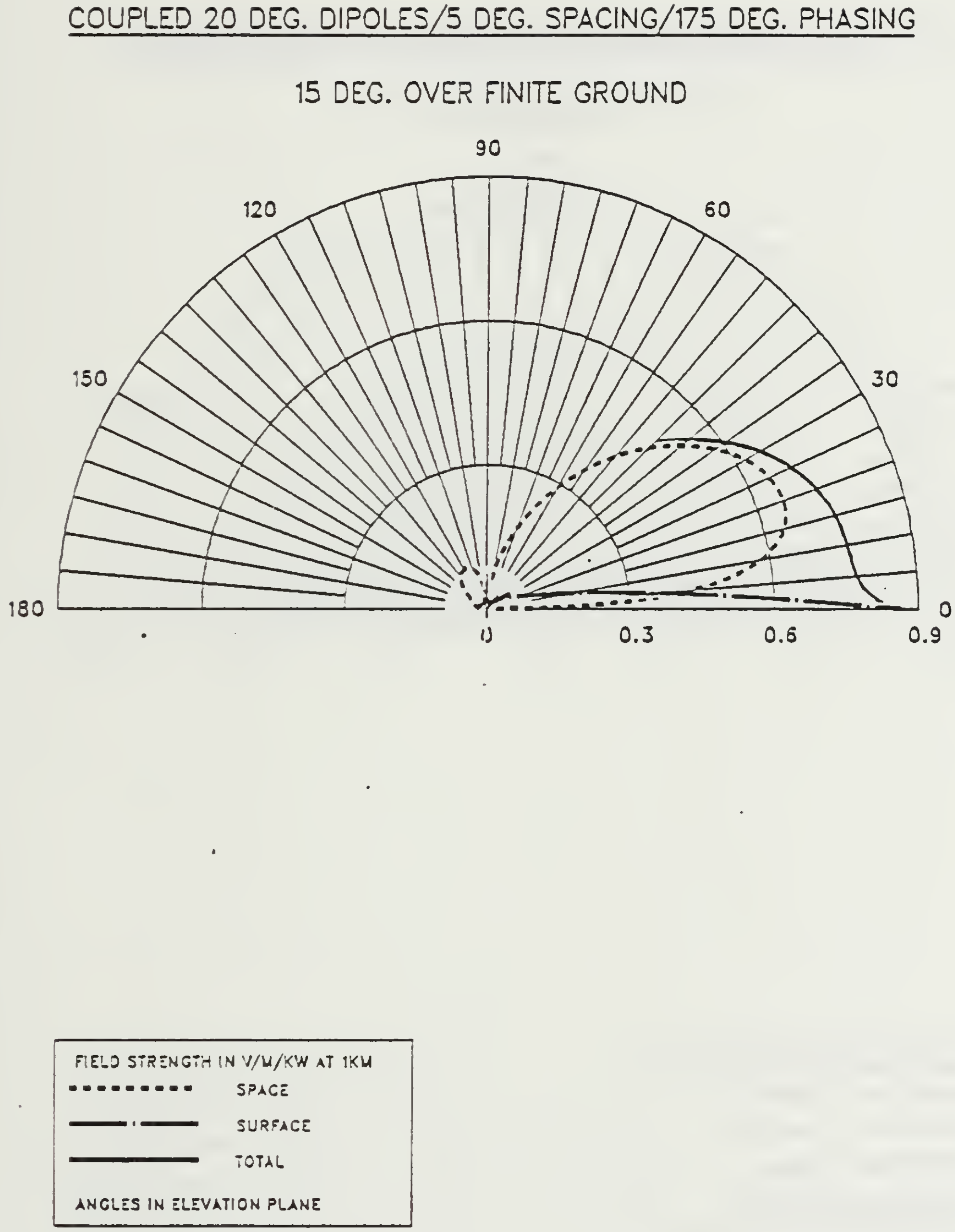


Figure A.32 Radiation Pattern - 20 Deg. Coupled Dipoles 15 Deg. over Finite Ground.

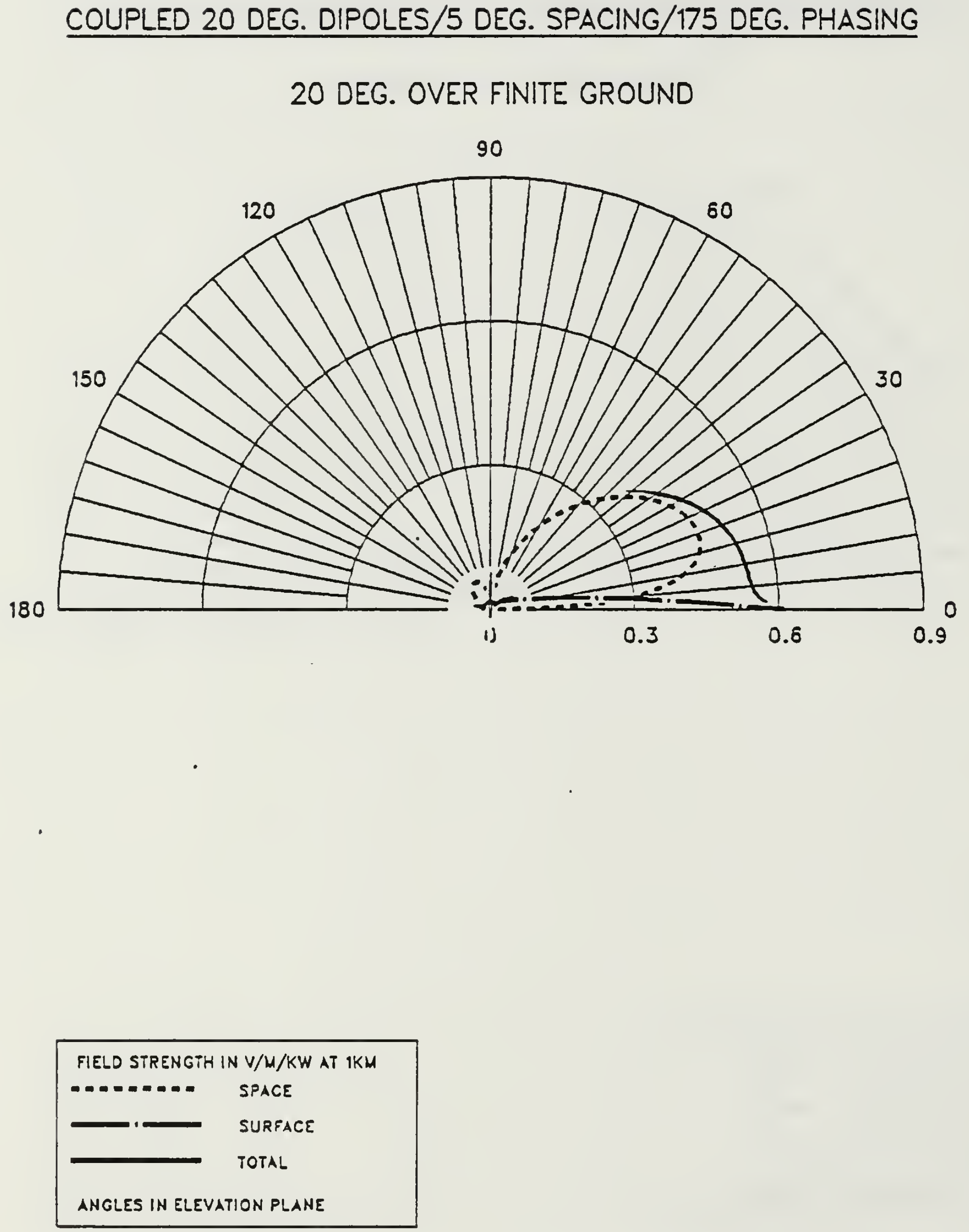


Figure A.33 Radiation Pattern - 20 Deg. Coupled Dipoles 20 Deg. over Finite Ground.

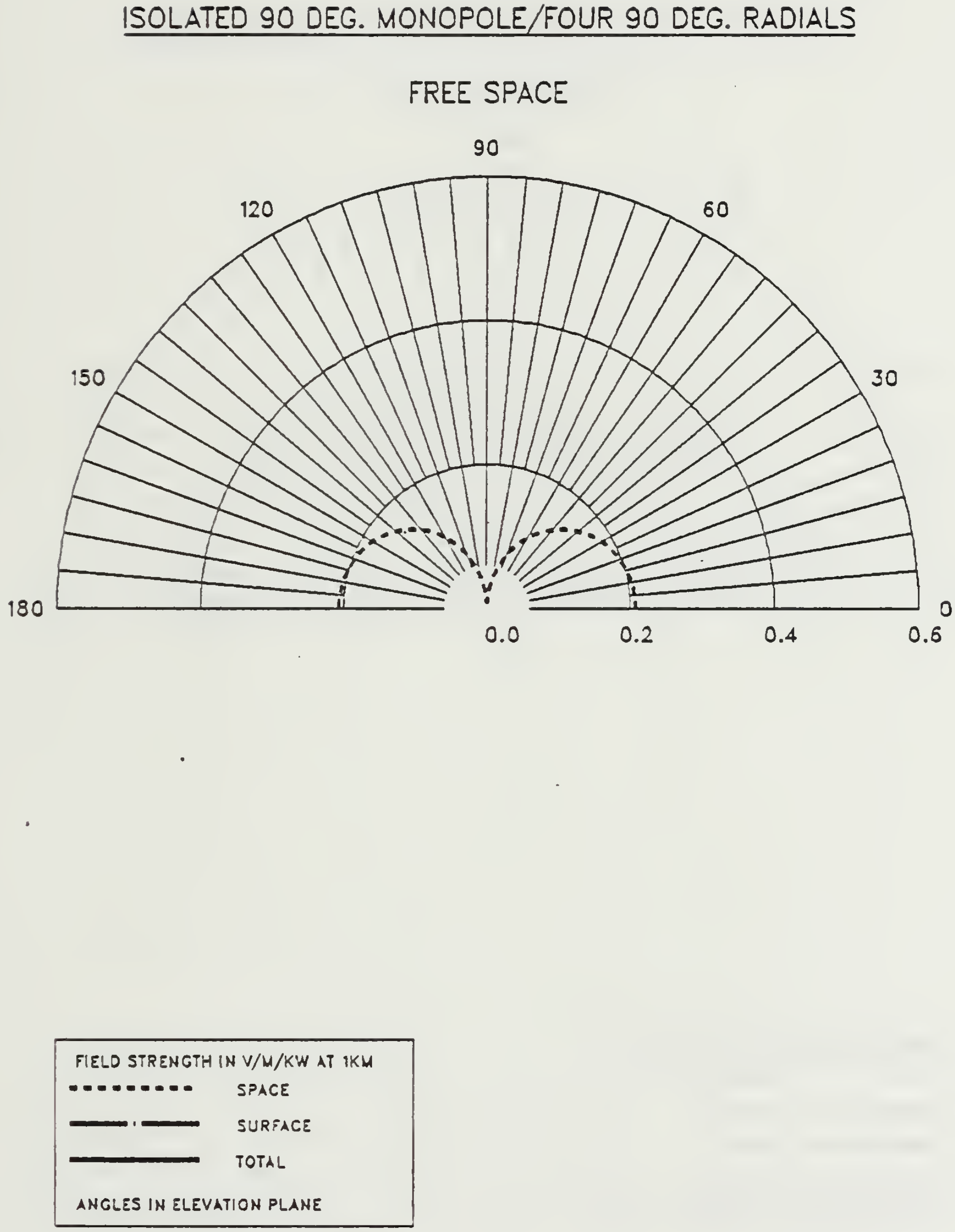


Figure A.34 Radiation Pattern - 90 Deg. Monopole in Free Space.

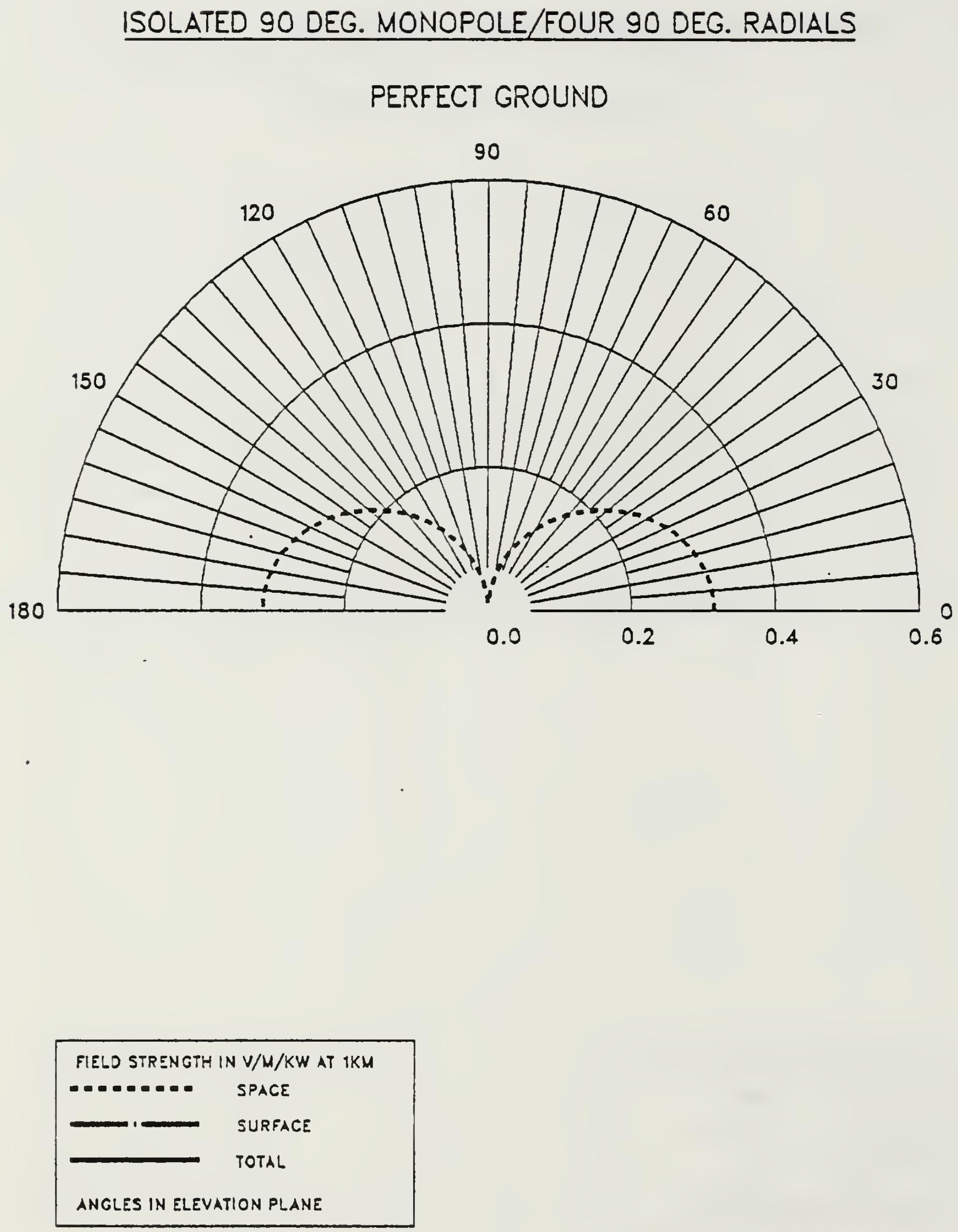


Figure A.35 Radiation Pattern - 90 Deg. Monopole over Perfect Ground.

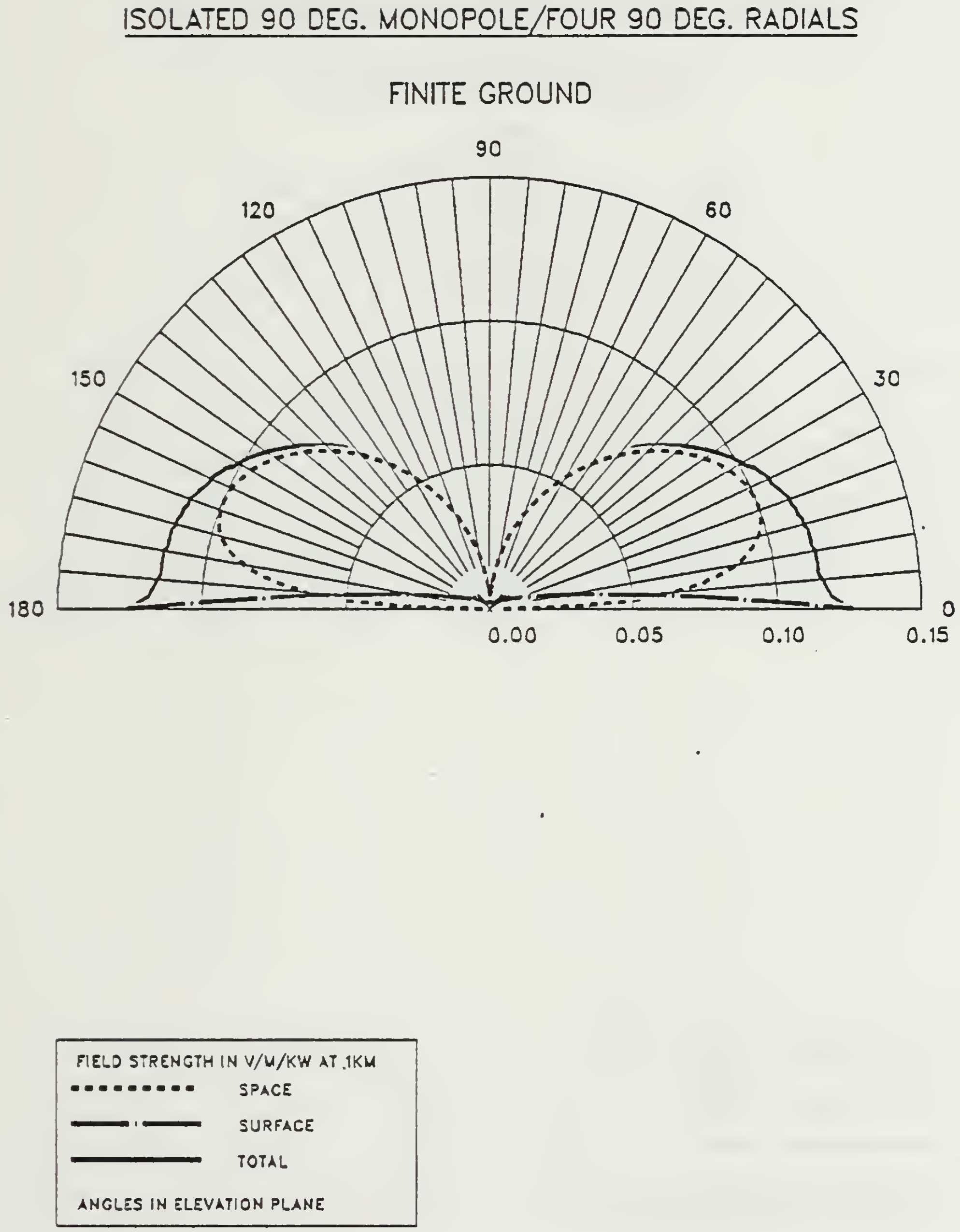


Figure A.36 Radiation Pattern - 90 Deg. Monopole over Finite Ground.

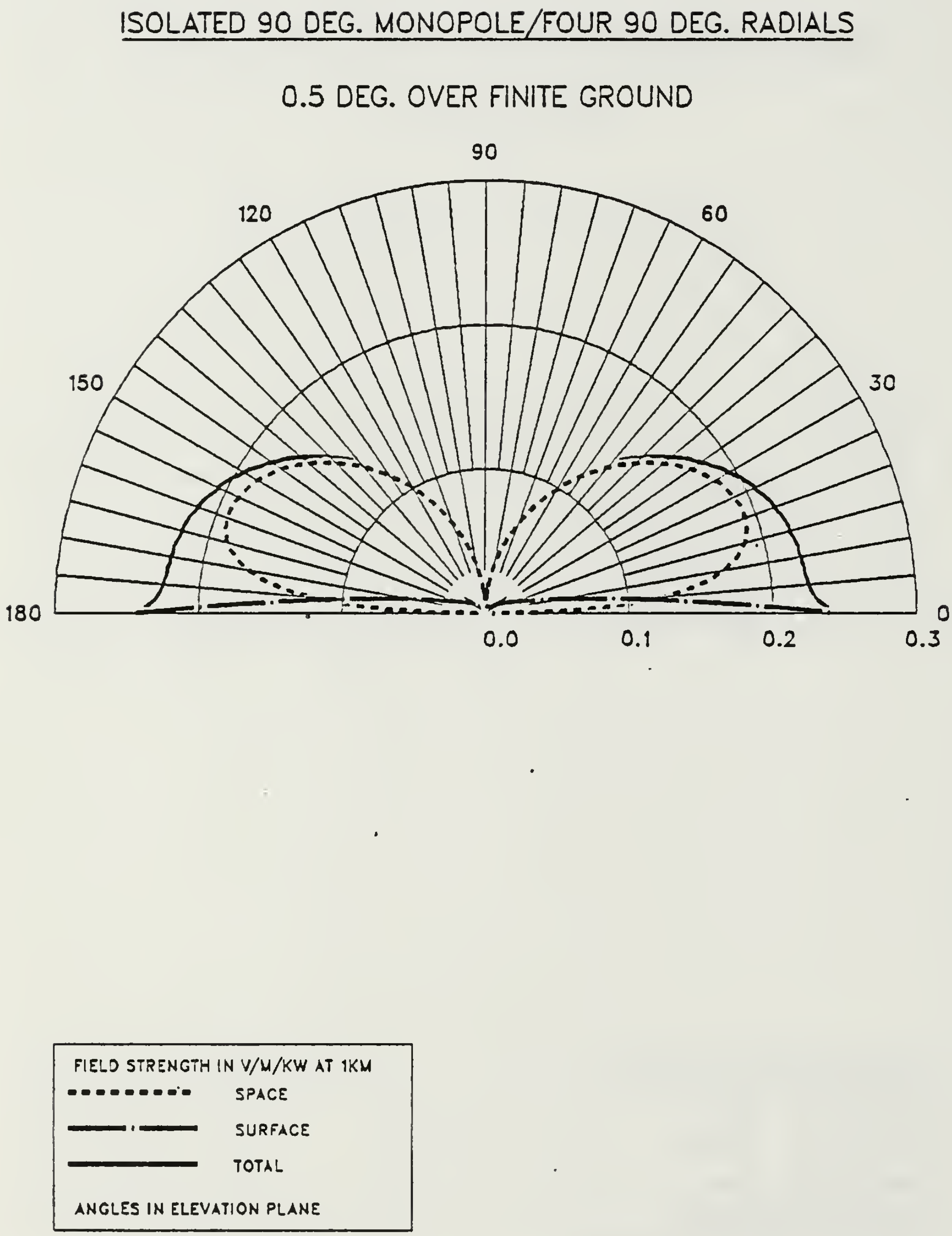


Figure A.37 Radiation Pattern - 90 Deg. Monopole 0.5 Deg. over Finite Ground.

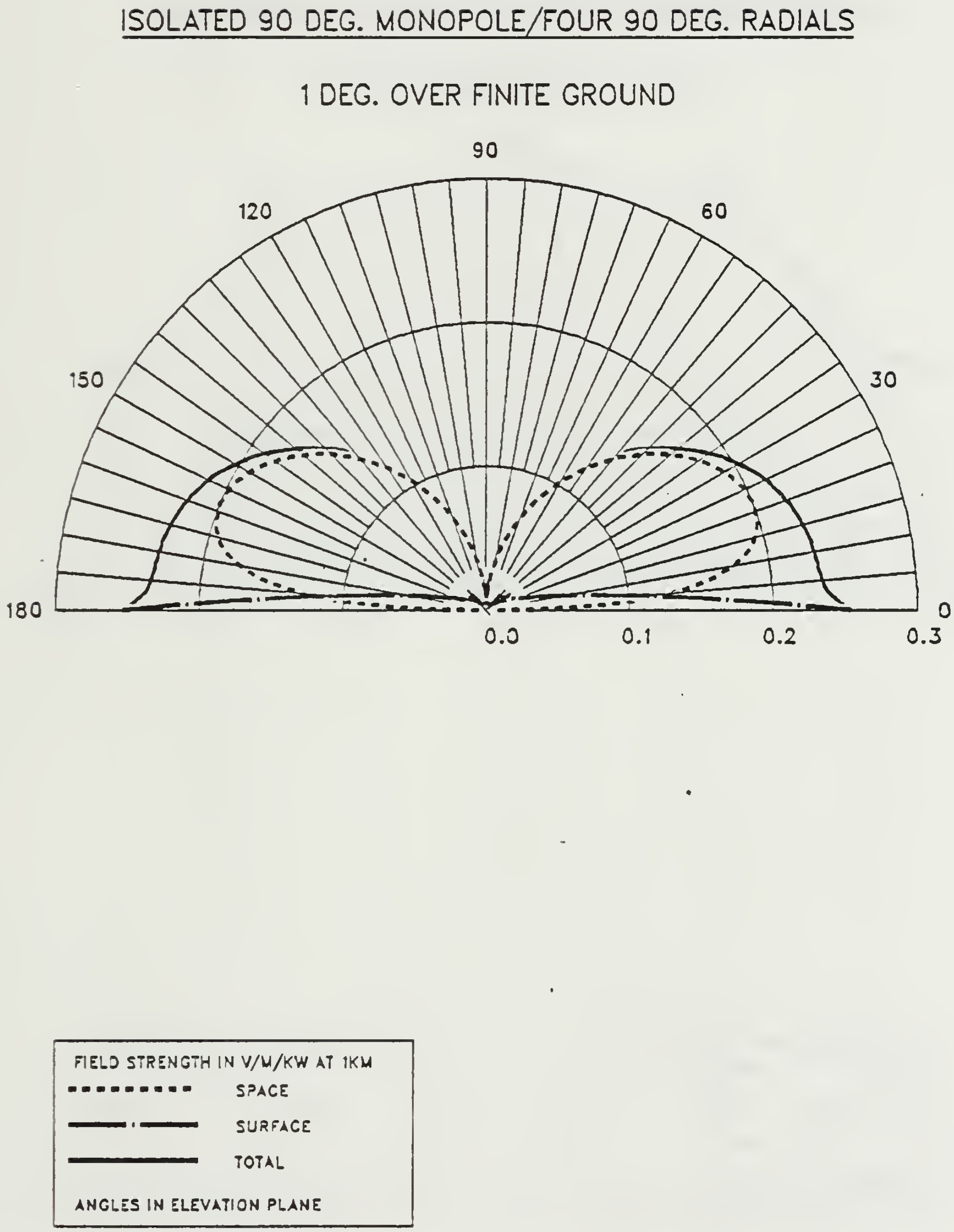


Figure A.38 Radiation Pattern - 90 Deg. Monopole 1 Deg. over Finite Ground.

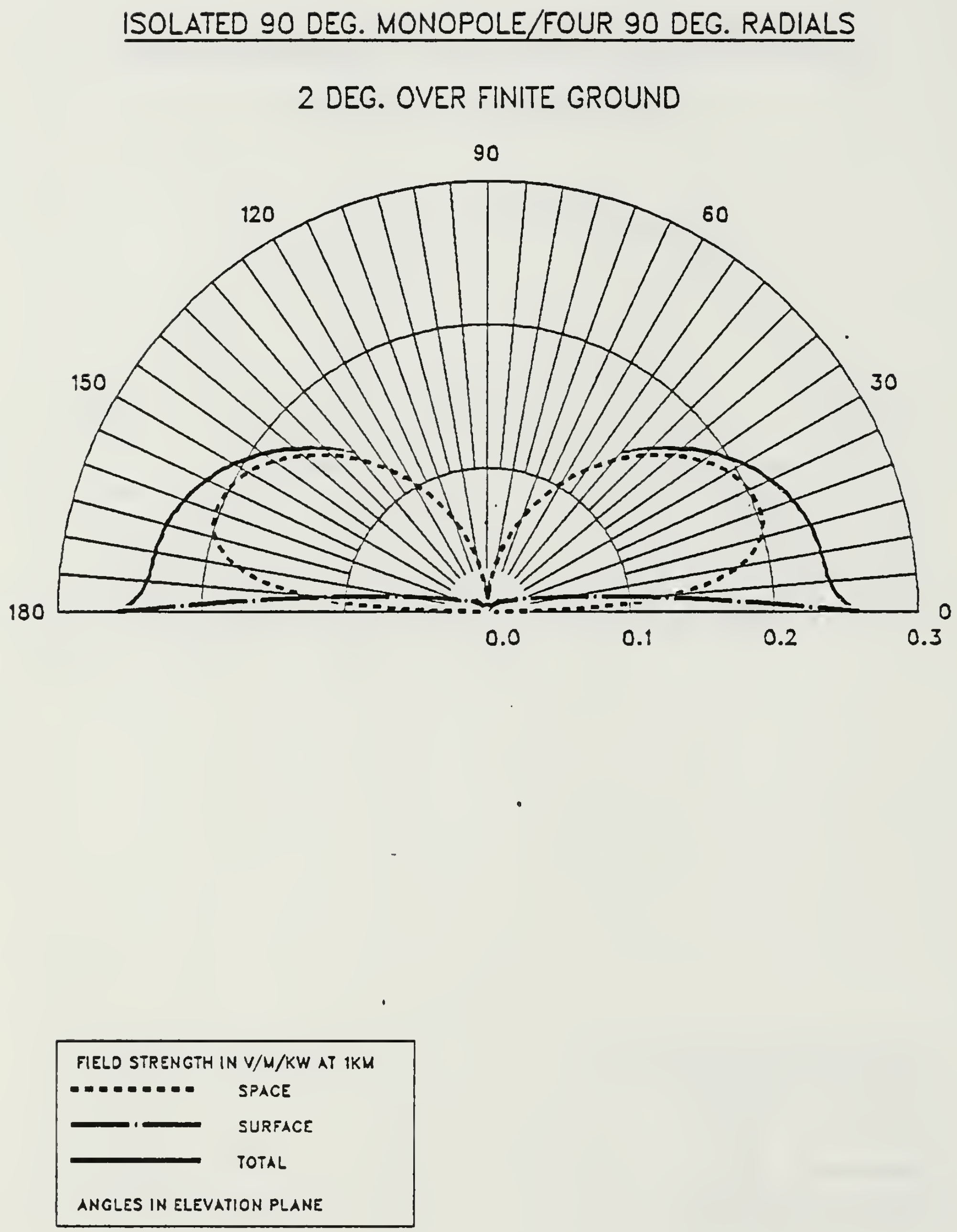


Figure A.39 Radiation Pattern - 90 Deg. Monopole 2 Deg. over Finite Ground.

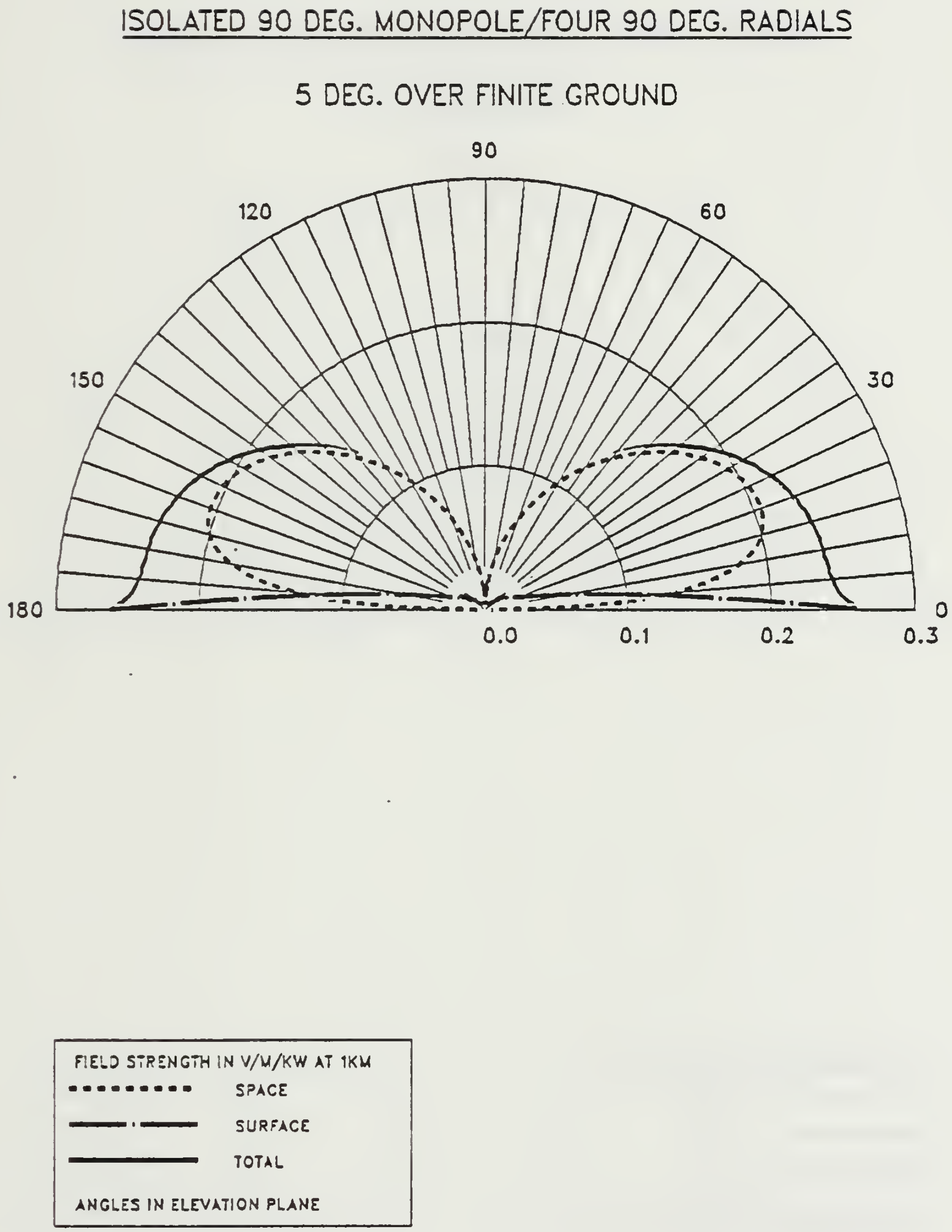


Figure A.40 Radiation Pattern - 90 Deg. Monopole 5 Deg. over Finite Ground.

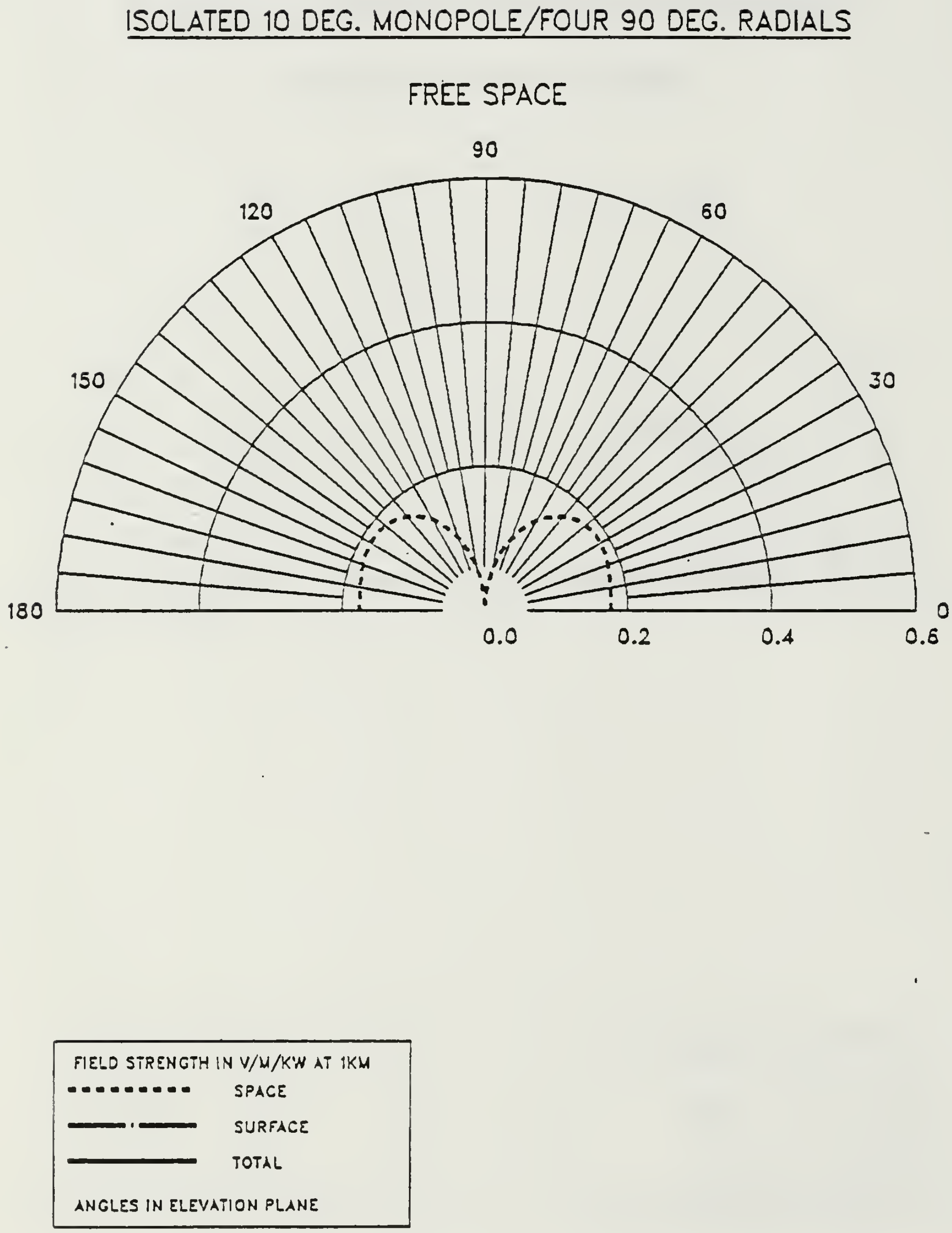


Figure A.41 Radiation Pattern - 10 Deg. Monopole in Free Space.

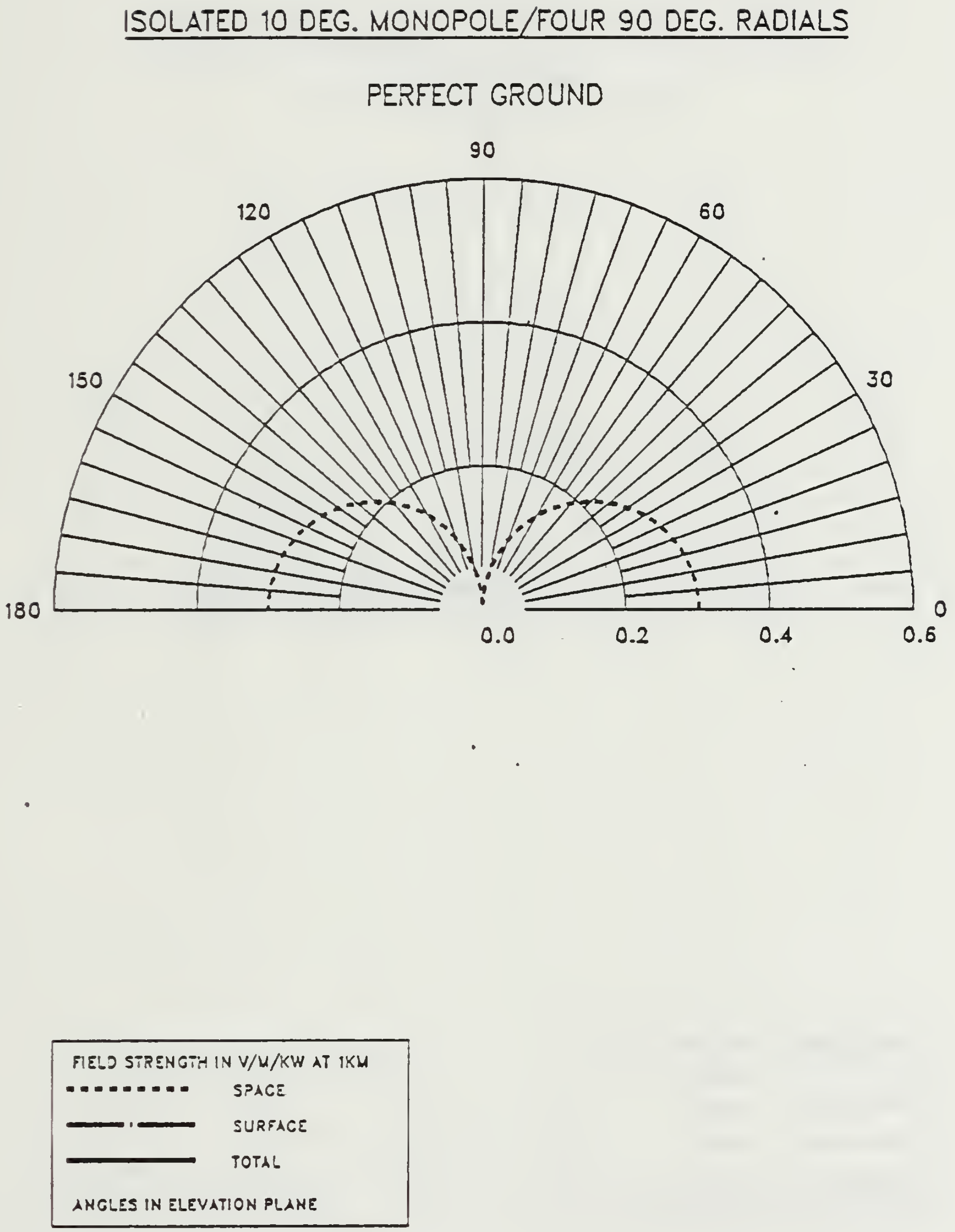


Figure A.42 Radiation Pattern - 10 Deg. Monopole over Perfect Ground.

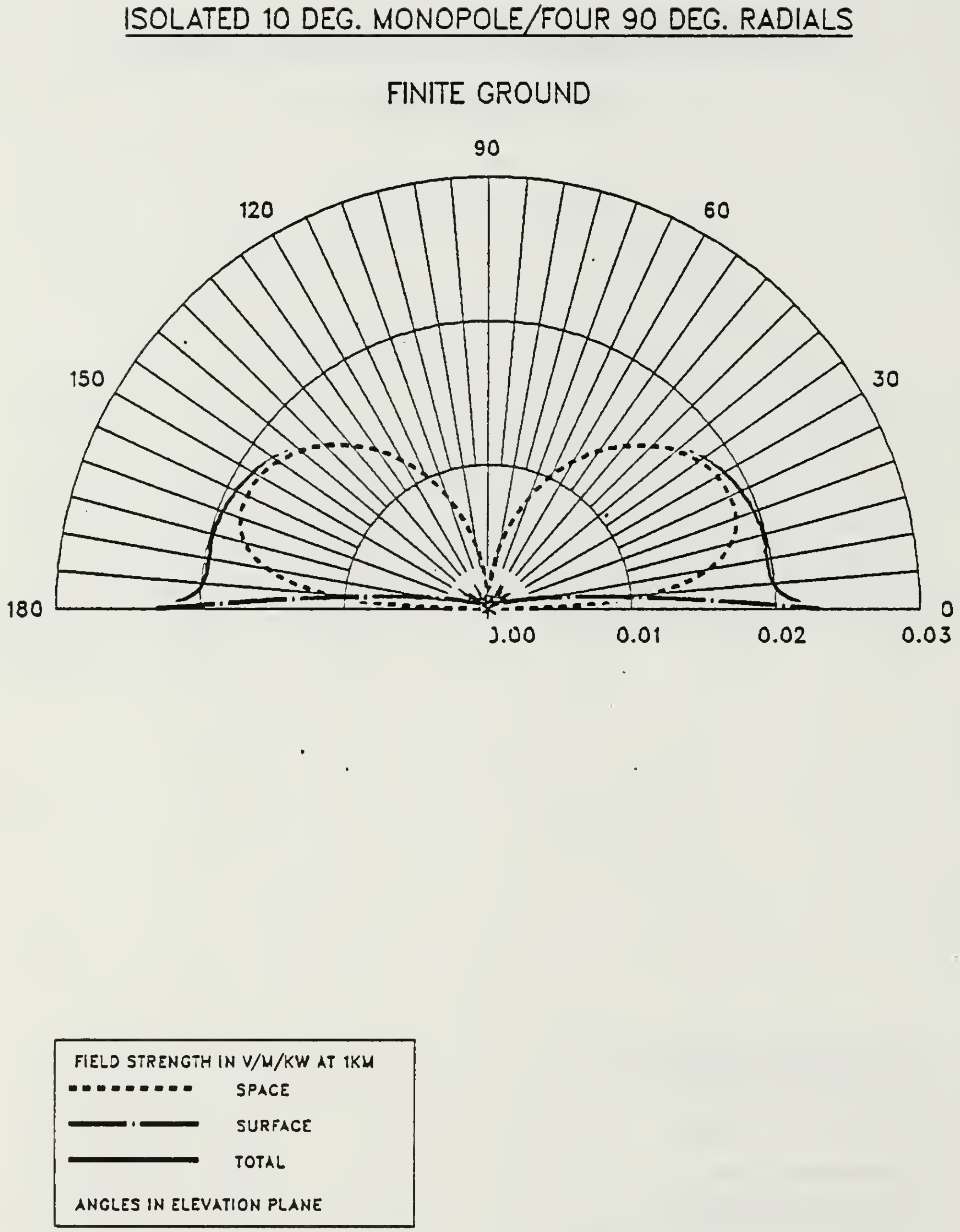


Figure A.43 Radiation Pattern - 10 Deg. Monopole over Finite Ground.

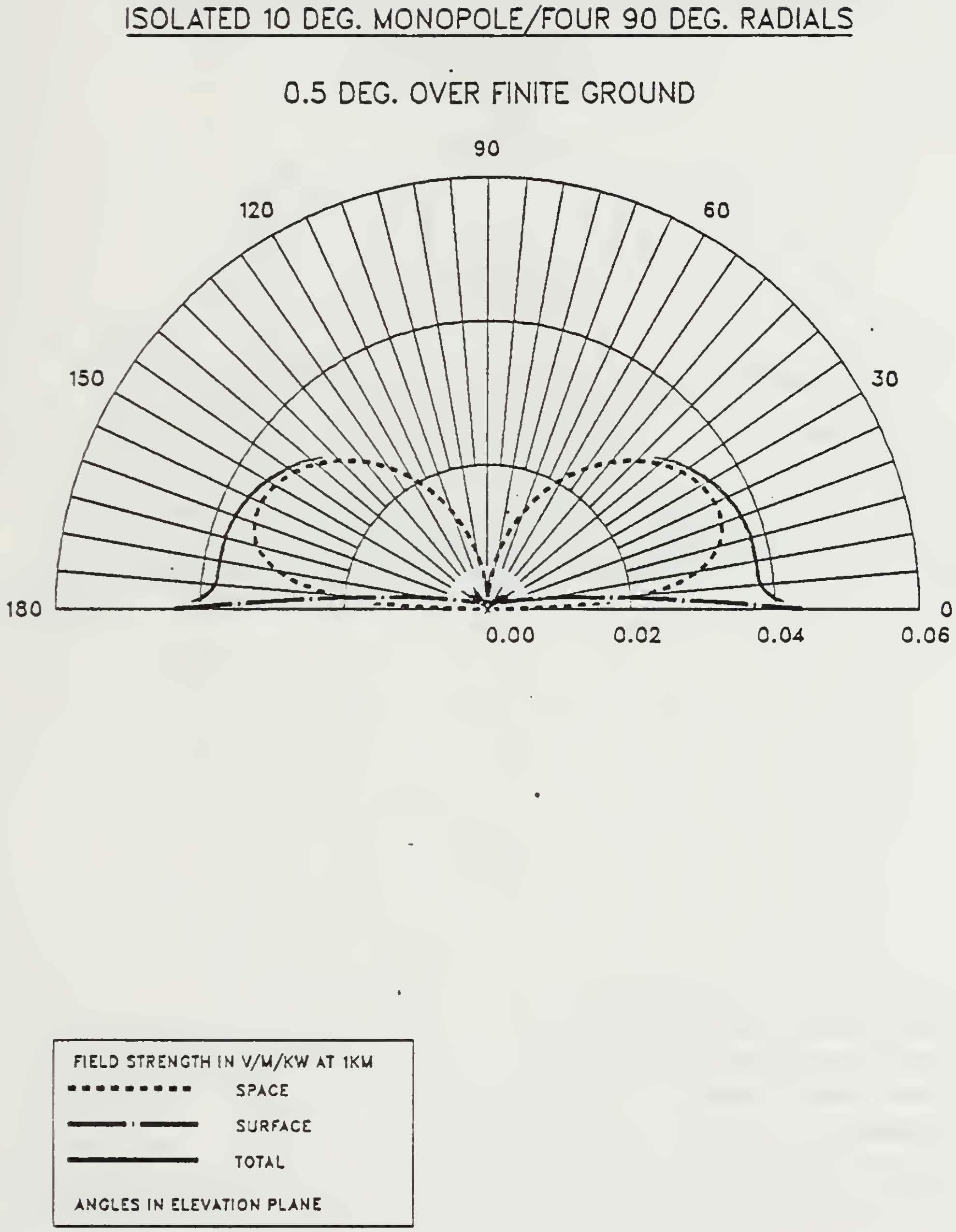


Figure A.44 Radiation Pattern - 10 Deg. Monopole 0.5 Deg. over Finite Ground.

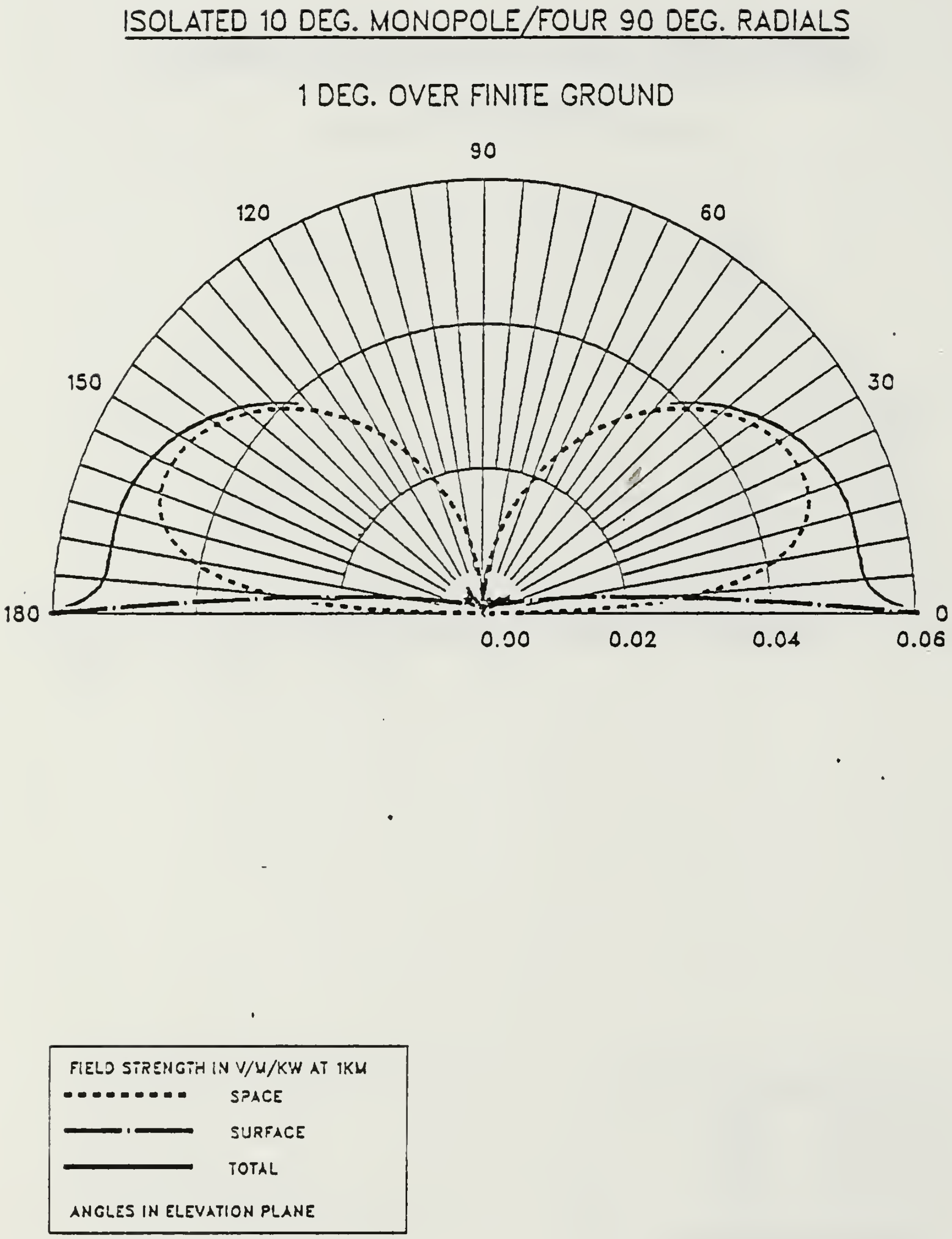


Figure A.45 Radiation Pattern - 10 Deg. Monopole 1 Deg. over Finite Ground.

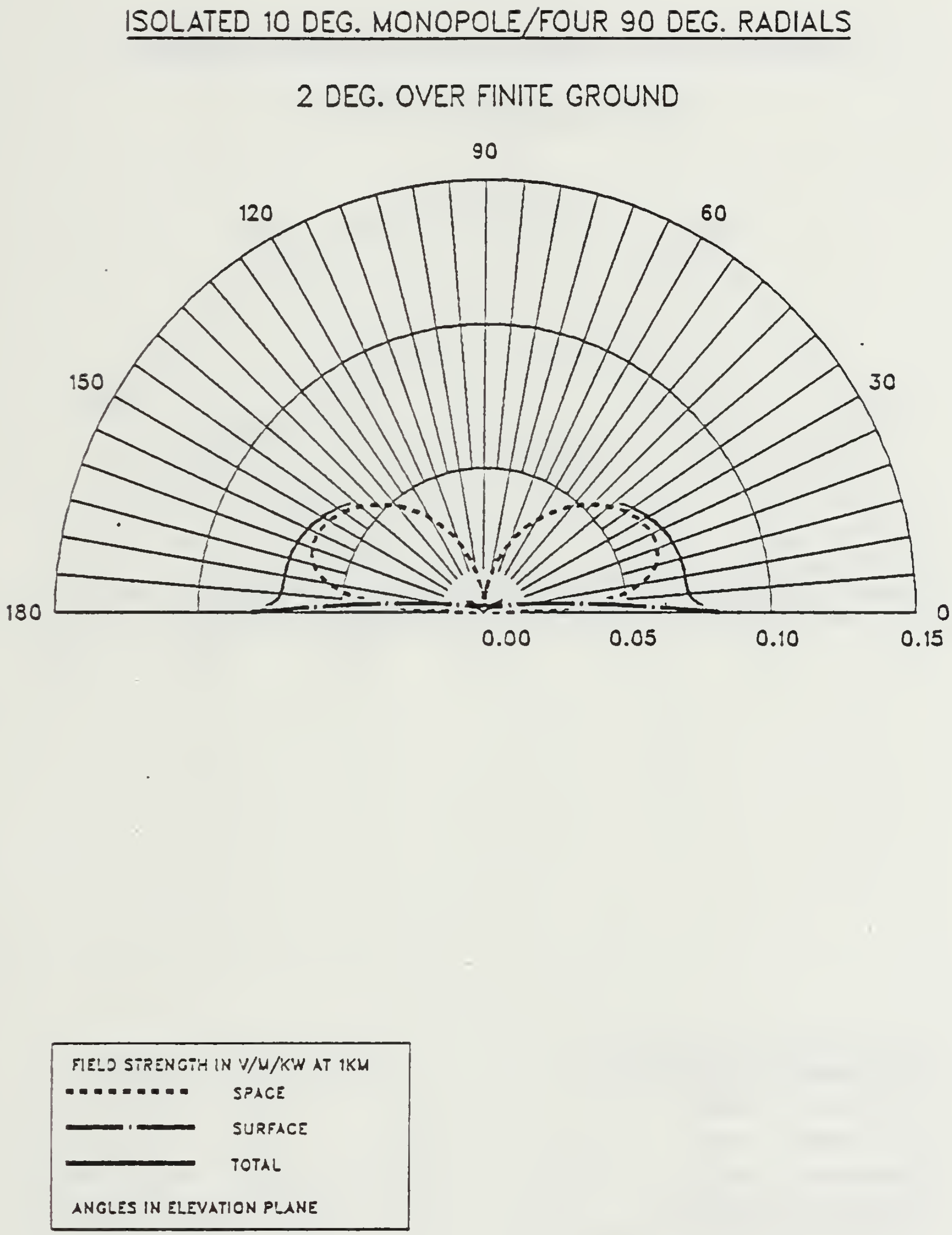


Figure A.46 Radiation Pattern - 10 Deg. Monopole 2 Deg. over Finite Ground.

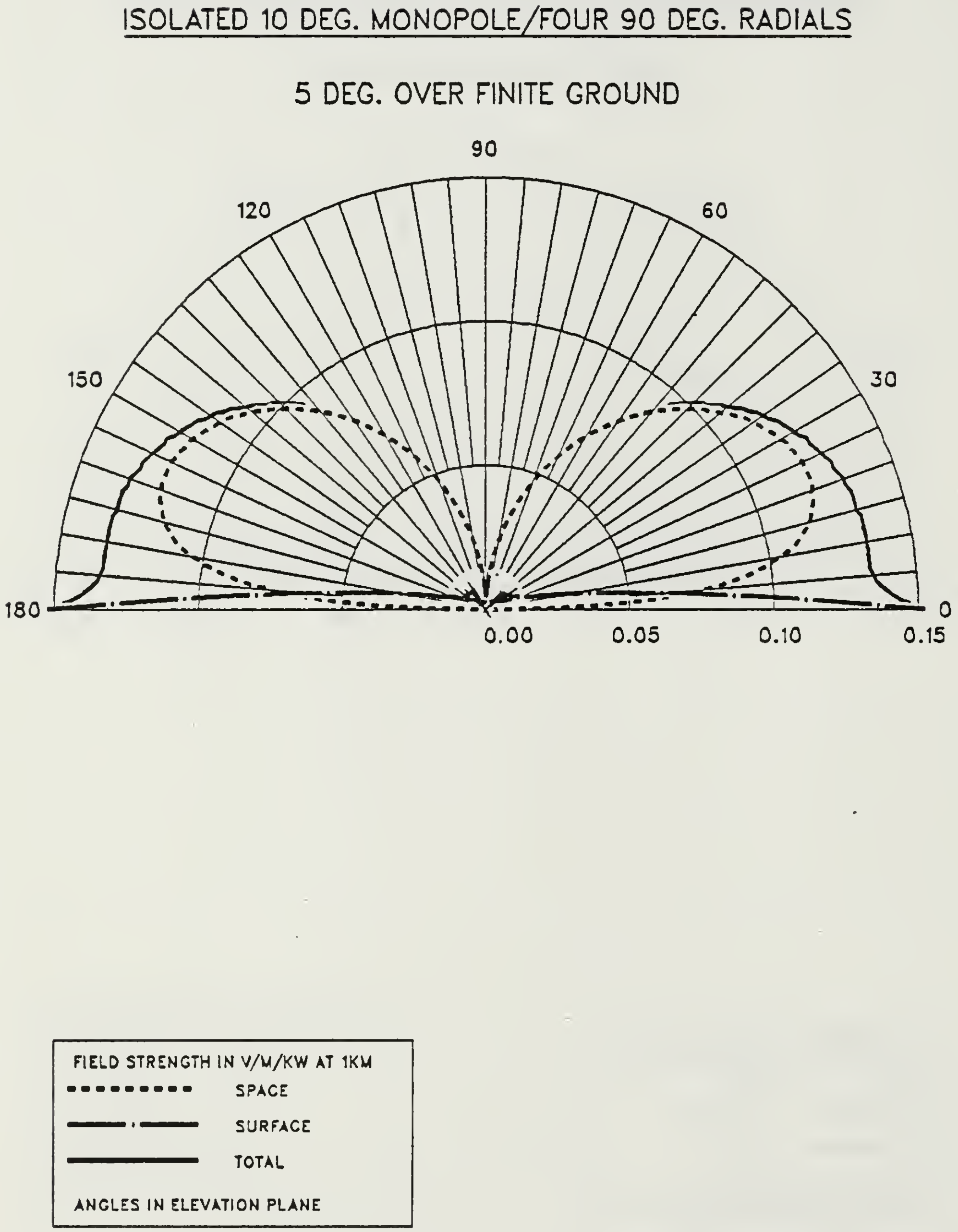


Figure A.47 Radiation Pattern - 10 Deg. Monopole 5 Deg. over Finite Ground.

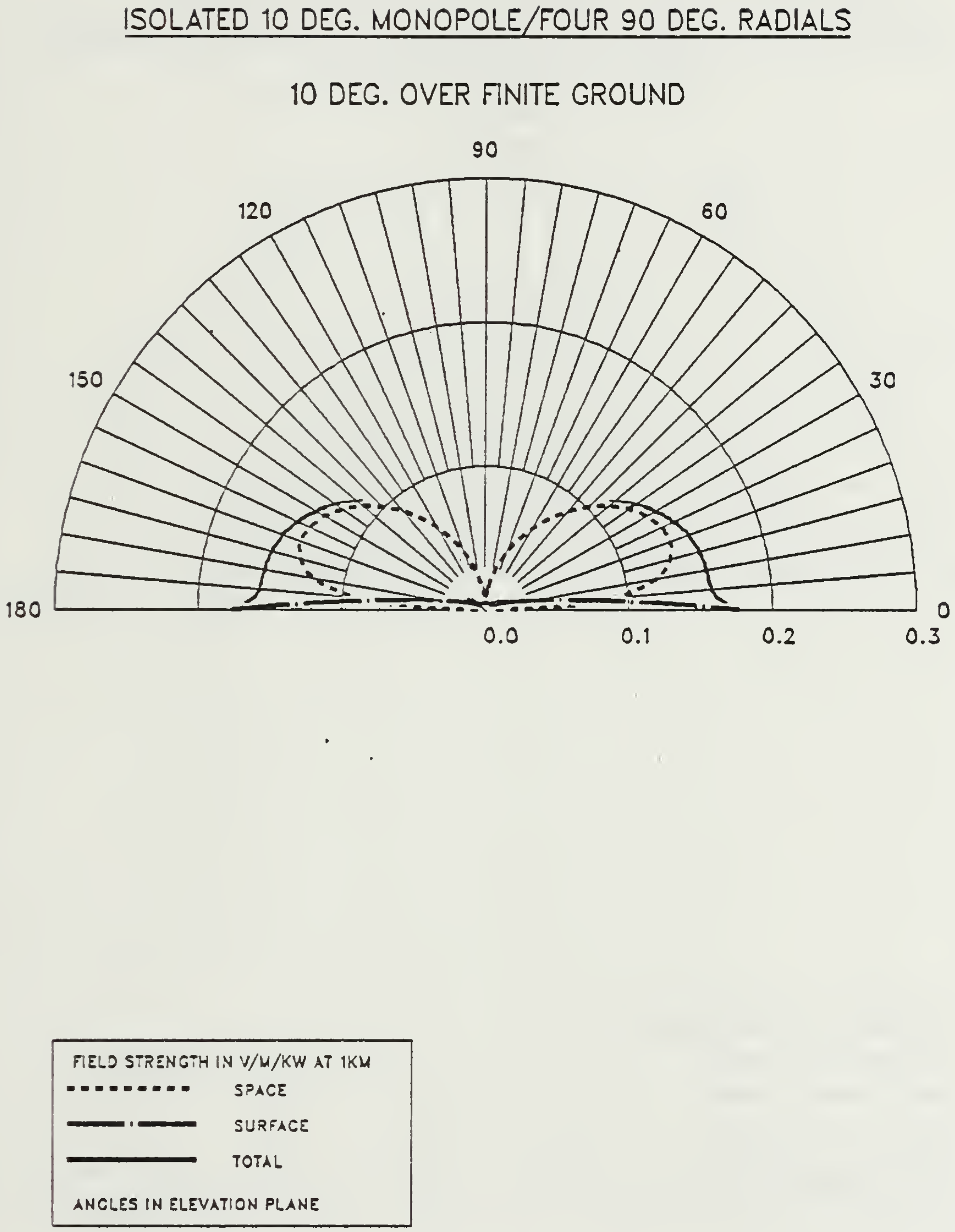


Figure A.48 Radiation Pattern - 10 Deg. Monopole 10 Deg. over Finite Ground.

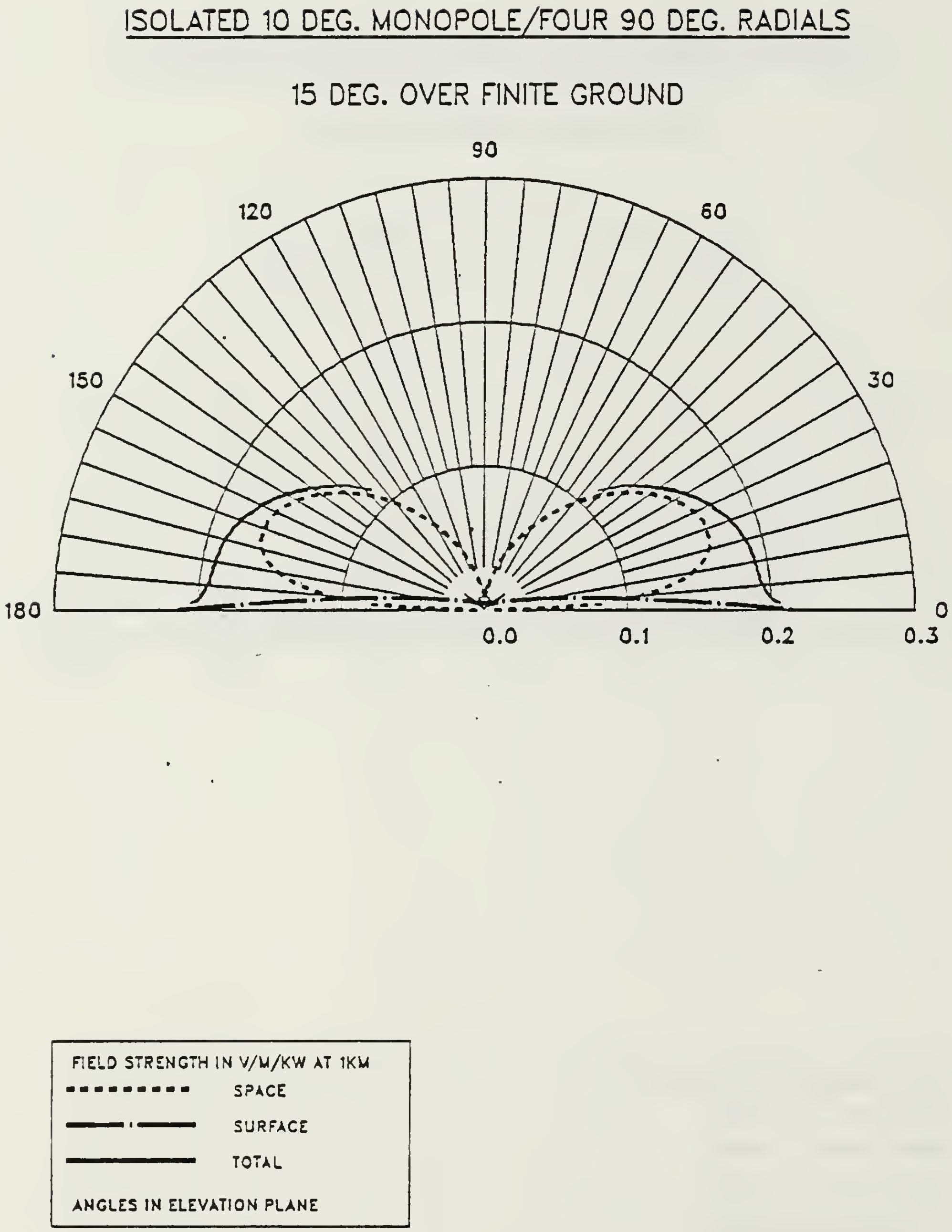


Figure A.49 Radiation Pattern - 10 Deg. Monopole 15 Deg. over Finite Ground.

COUPLED 90 DEG. MONOPOLES/5 DEG. SPACING/175 DEG. PHASING

SIX 90 DEG. RADIALS/FREE SPACE

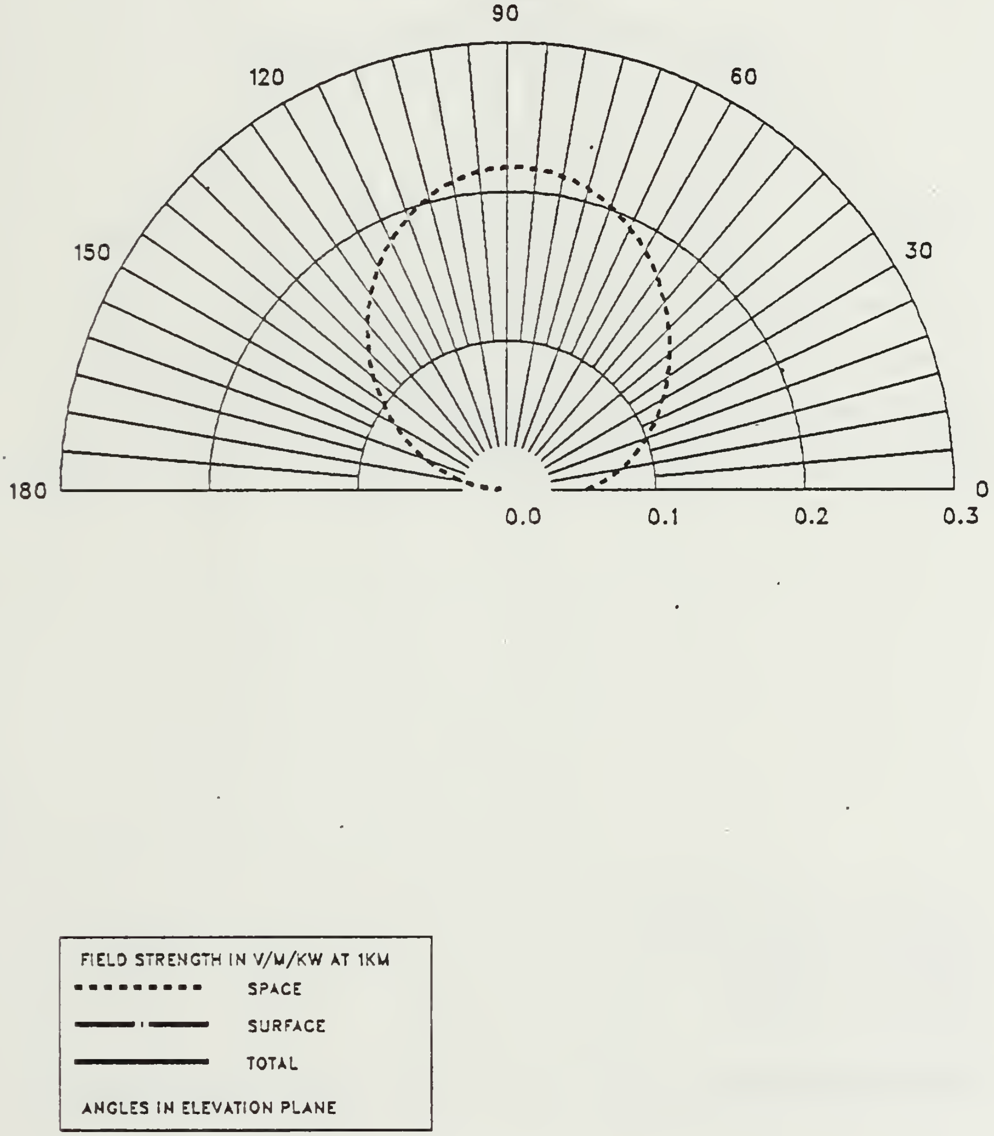


Figure A.50 Radiation Pattern - 90 Deg. Coupled Monopoles in Free Space.

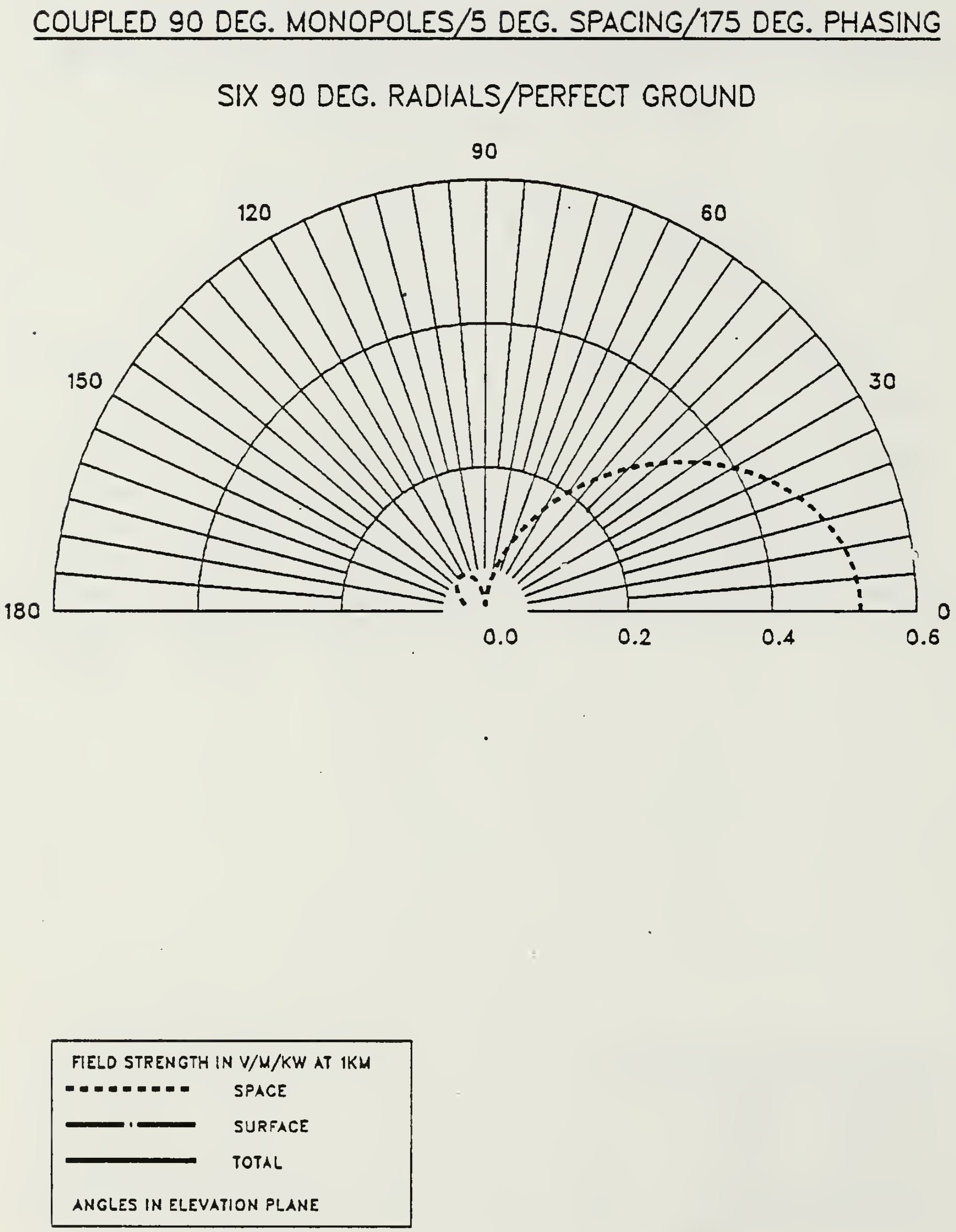


Figure A.51 Radiation Pattern - 90 Deg. Coupled Monopoles over Perfect Ground.

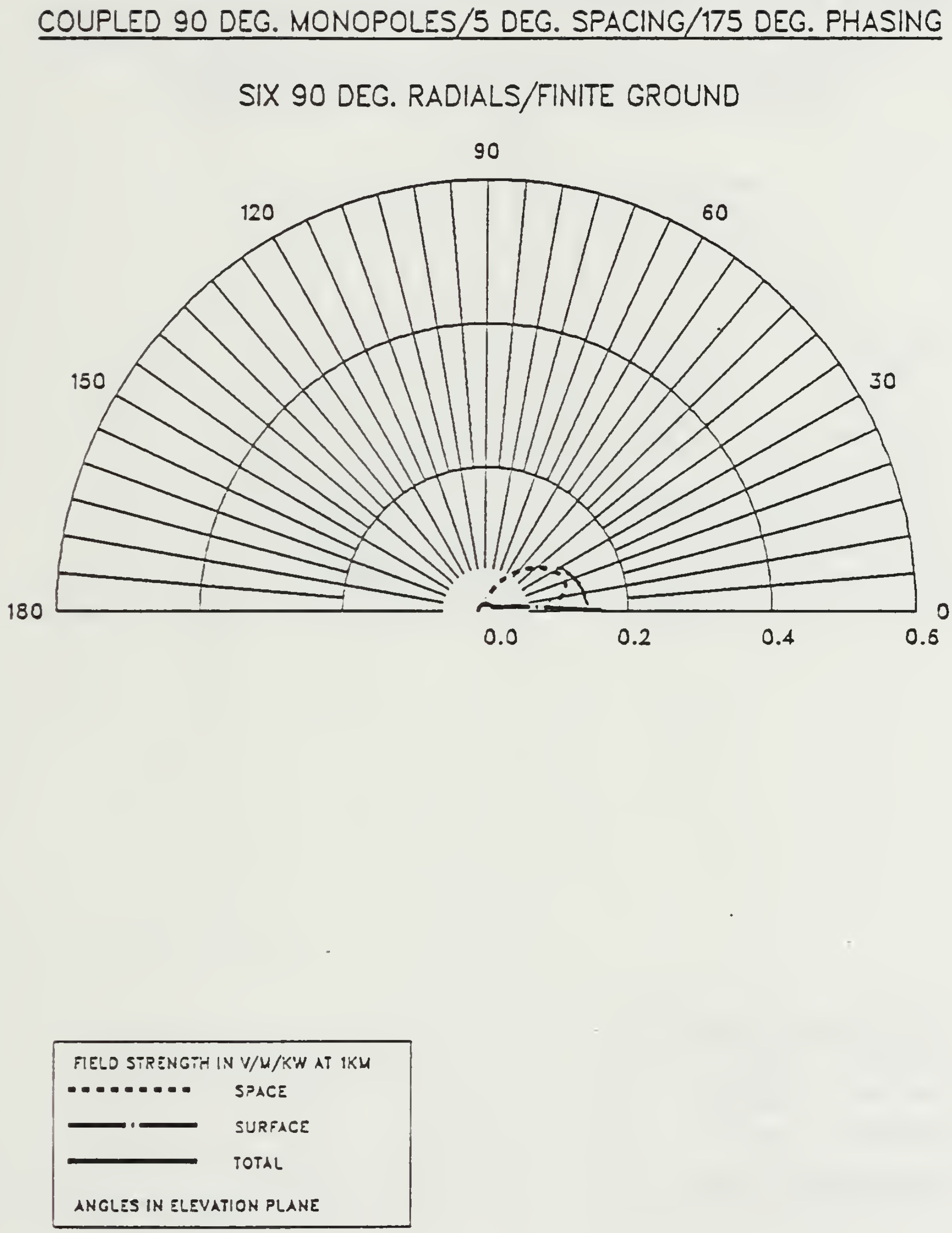


Figure A.52 Radiation Pattern - 90 Deg. Coupled Monopoles over Finite Ground.

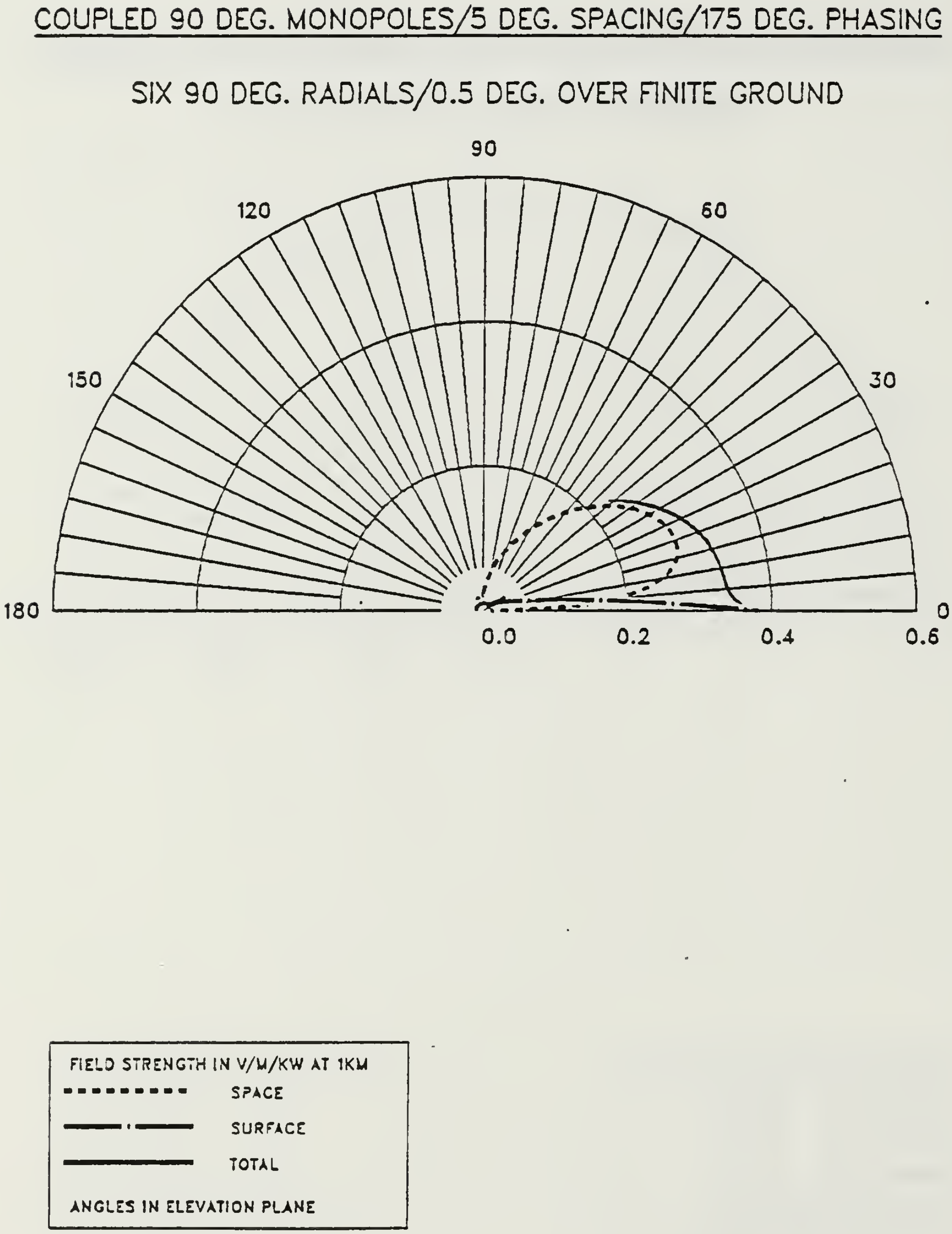


Figure A.53 Radiation Pattern - 90 Deg. Coupled Monopoles 0.5 Deg. over Finite Ground.

COUPLED 90 DEG. MONOPOLES/5 DEG. SPACING/175 DEG. PHASING

SIX 90 DEG. RADIALS/1 DEG. OVER FINITE GROUND

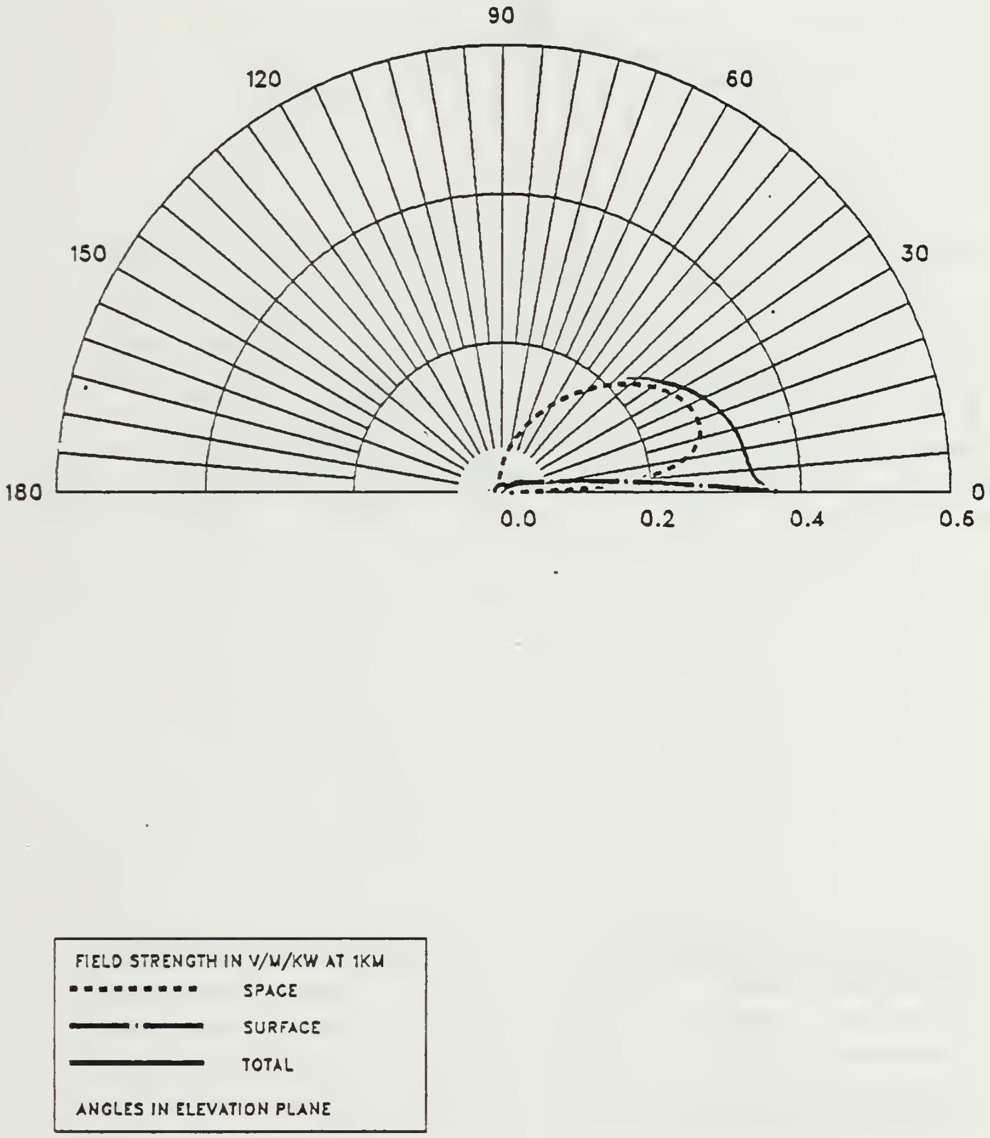


Figure A.54 Radiation Pattern - 90 Deg. Coupled Monopoles 1 Deg. over Finite Ground.

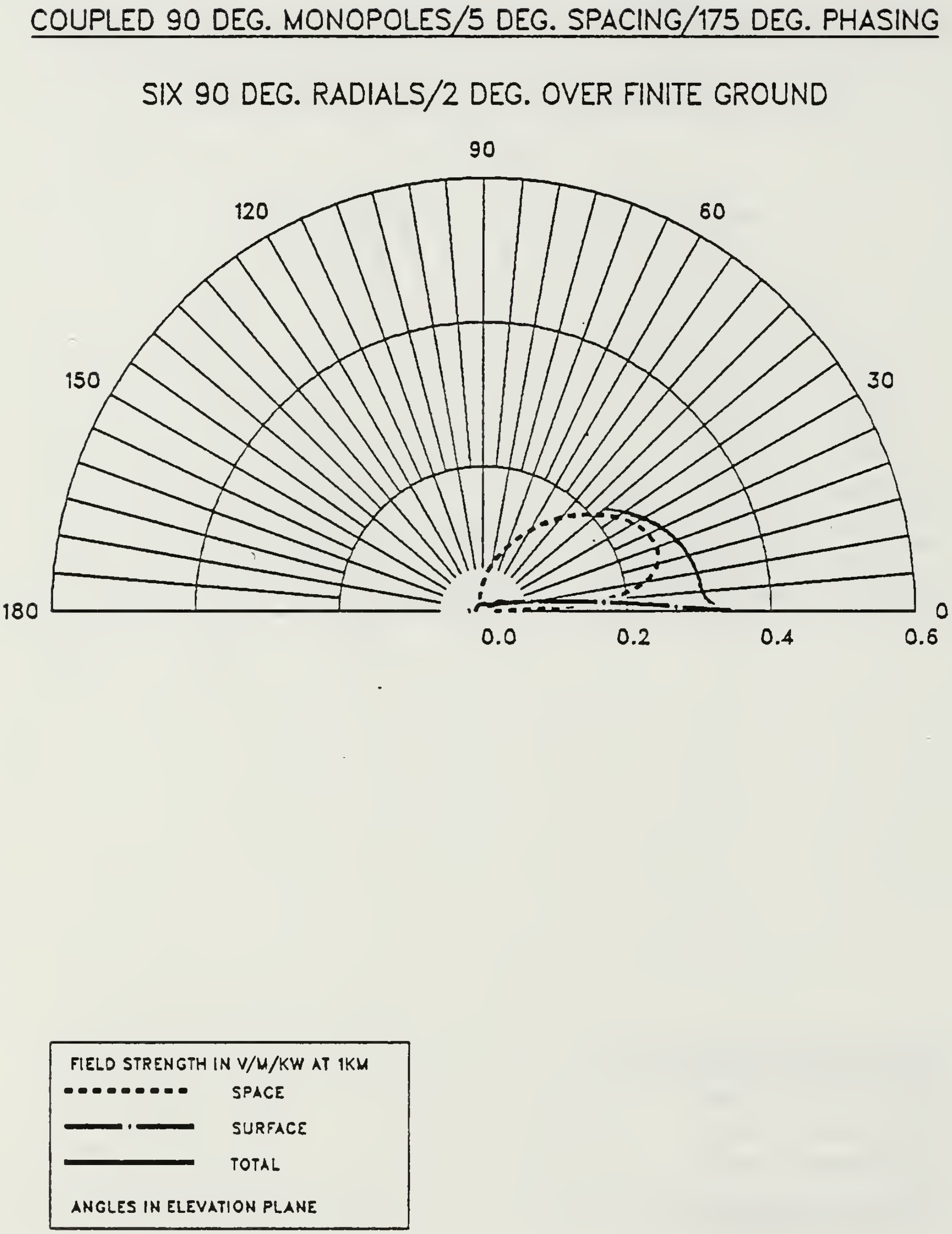


Figure A.55 Radiation Pattern - 90 Deg. Coupled Monopoles 2 Deg. over Finite Ground.

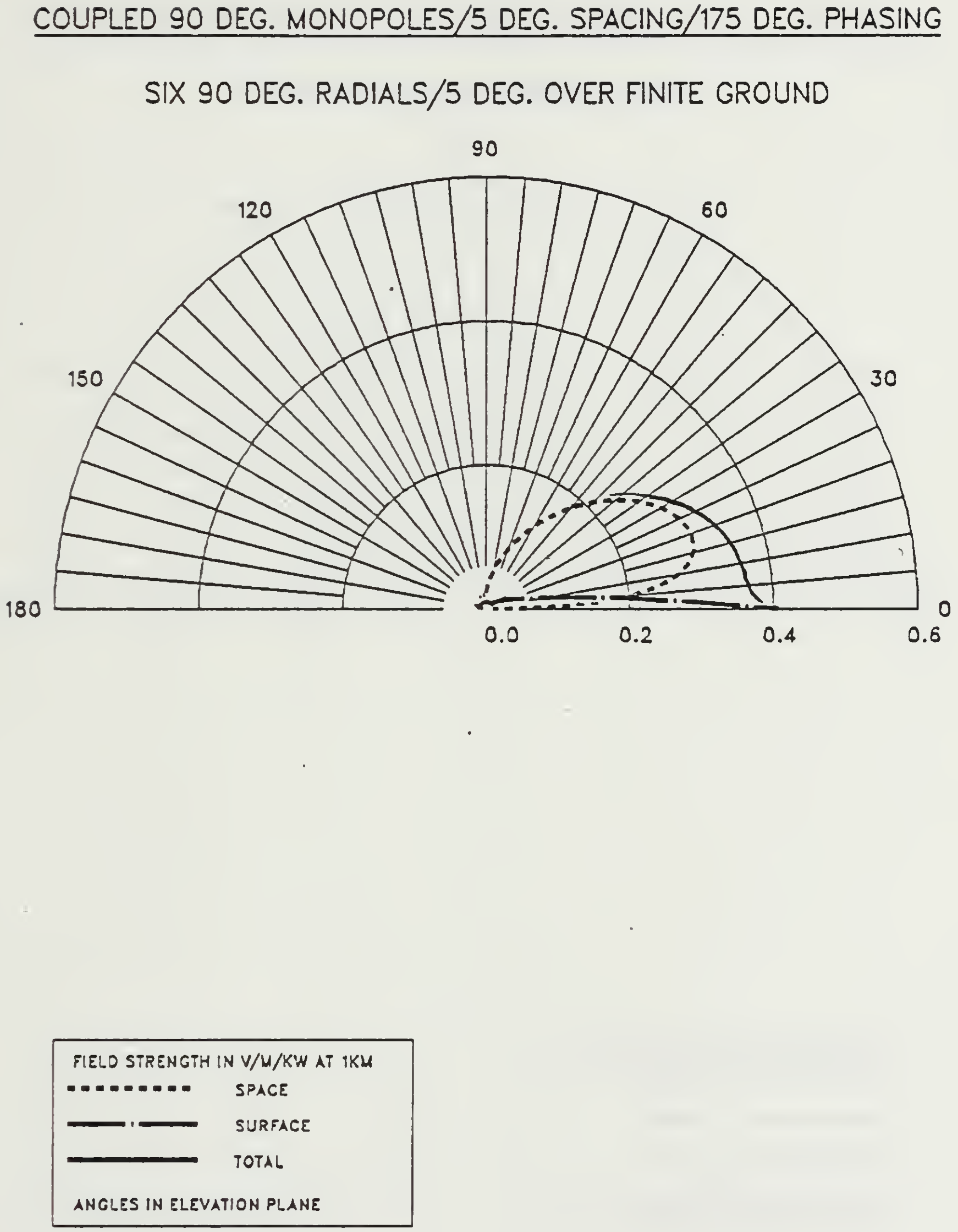


Figure A.56 Radiation Pattern - 90 Deg. Coupled Monopoles 5 Deg. over Finite Ground.

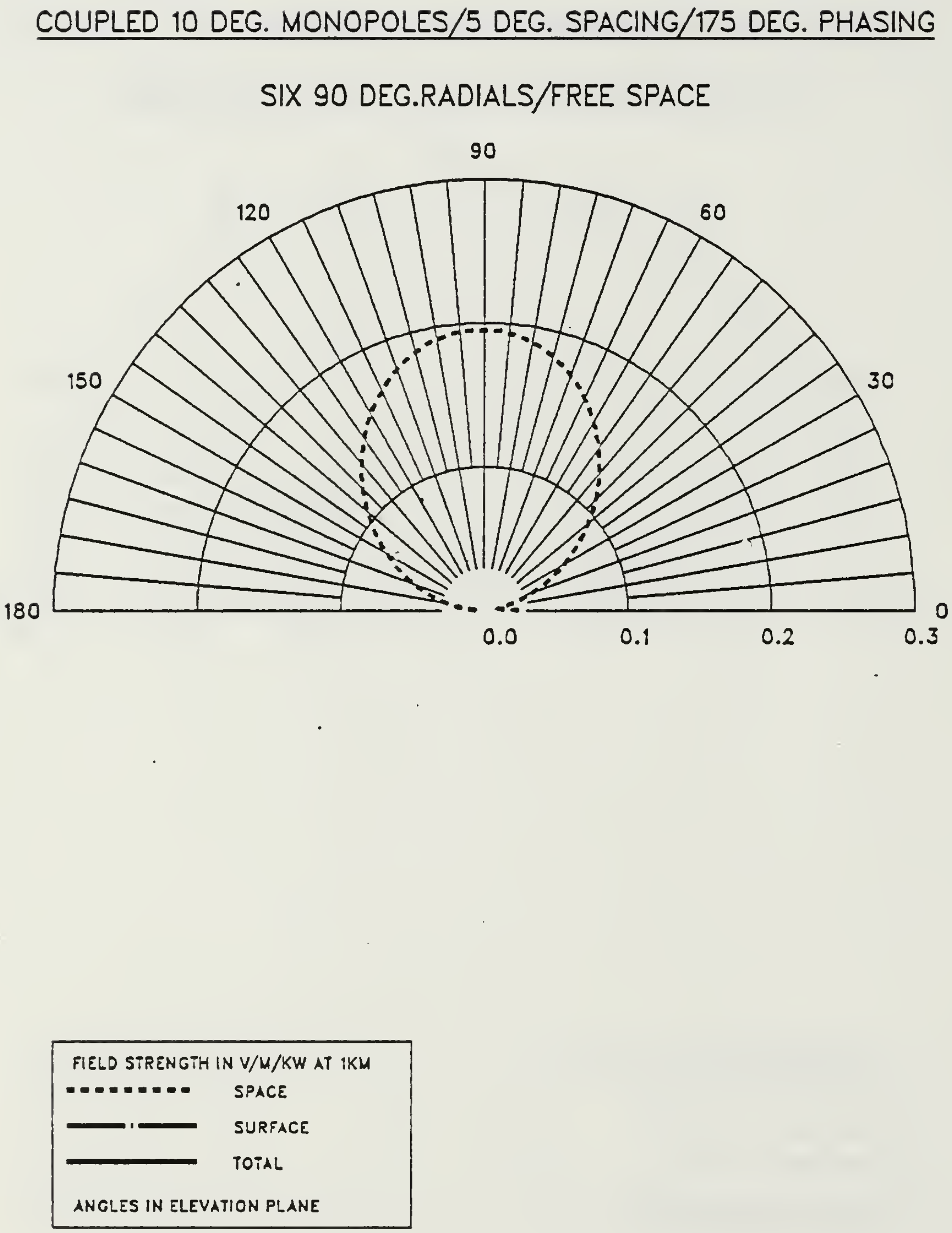


Figure A.57 Radiation Pattern - 10 Deg. Coupled Monopoles in Free Space.

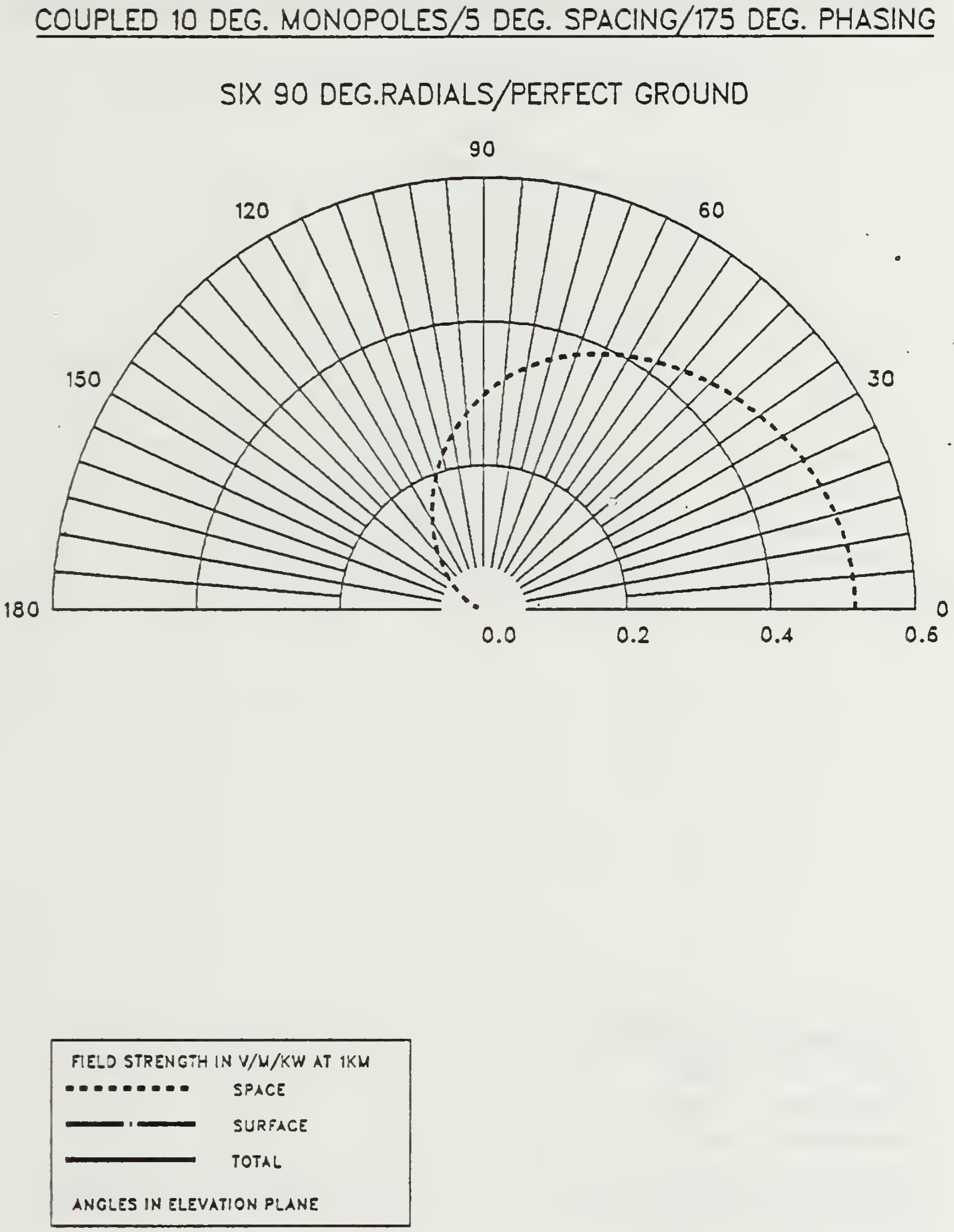


Figure A.58 Radiation Pattern - 10 Deg. Coupled Monopoles over Perfect Ground.

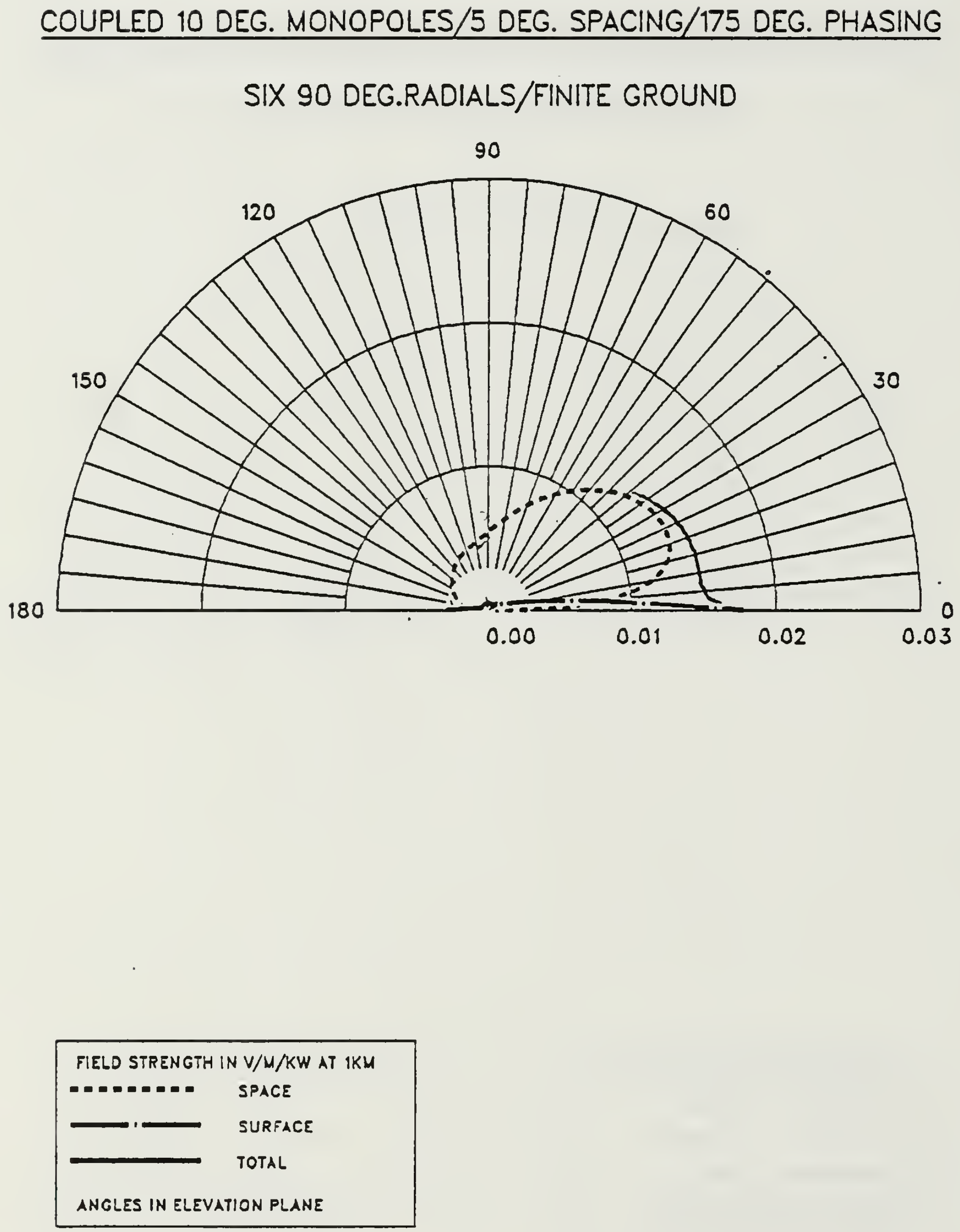
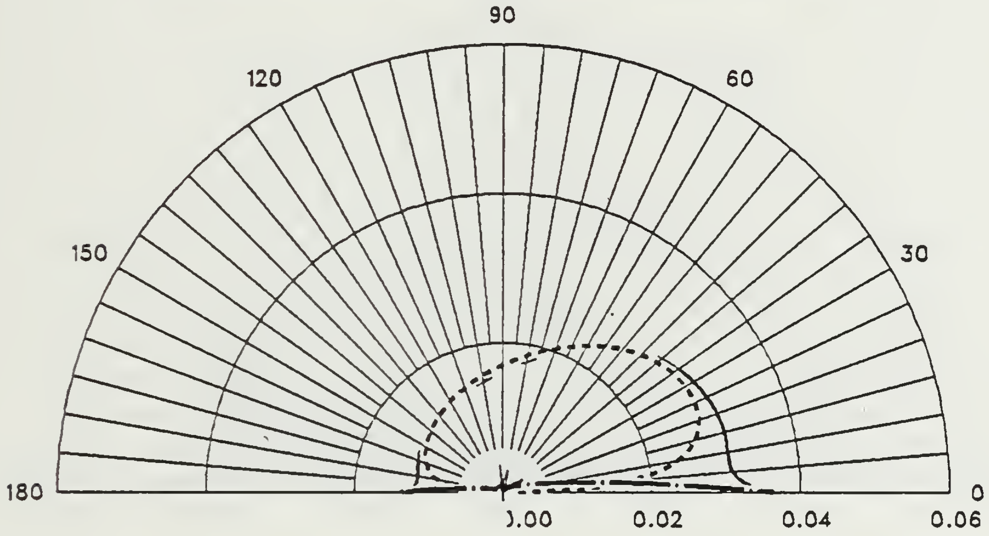


Figure A.59 Radiation Pattern - 10 Deg. Coupled Monopoles over Finite Ground.

COUPLED 10 DEG. MONOPOLES/5 DEG. SPACING/175 DEG. PHASING

SIX 90 DEG.RADIALS/0.5 DEG. OVER FINITE GROUND



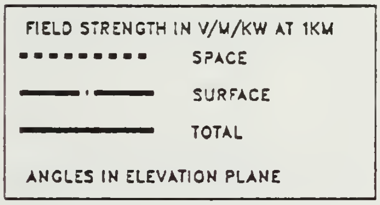


Figure A.60 Radiation Pattern - 10 Deg. Coupled Monopoles 0.5 Deg. over Finite Ground.

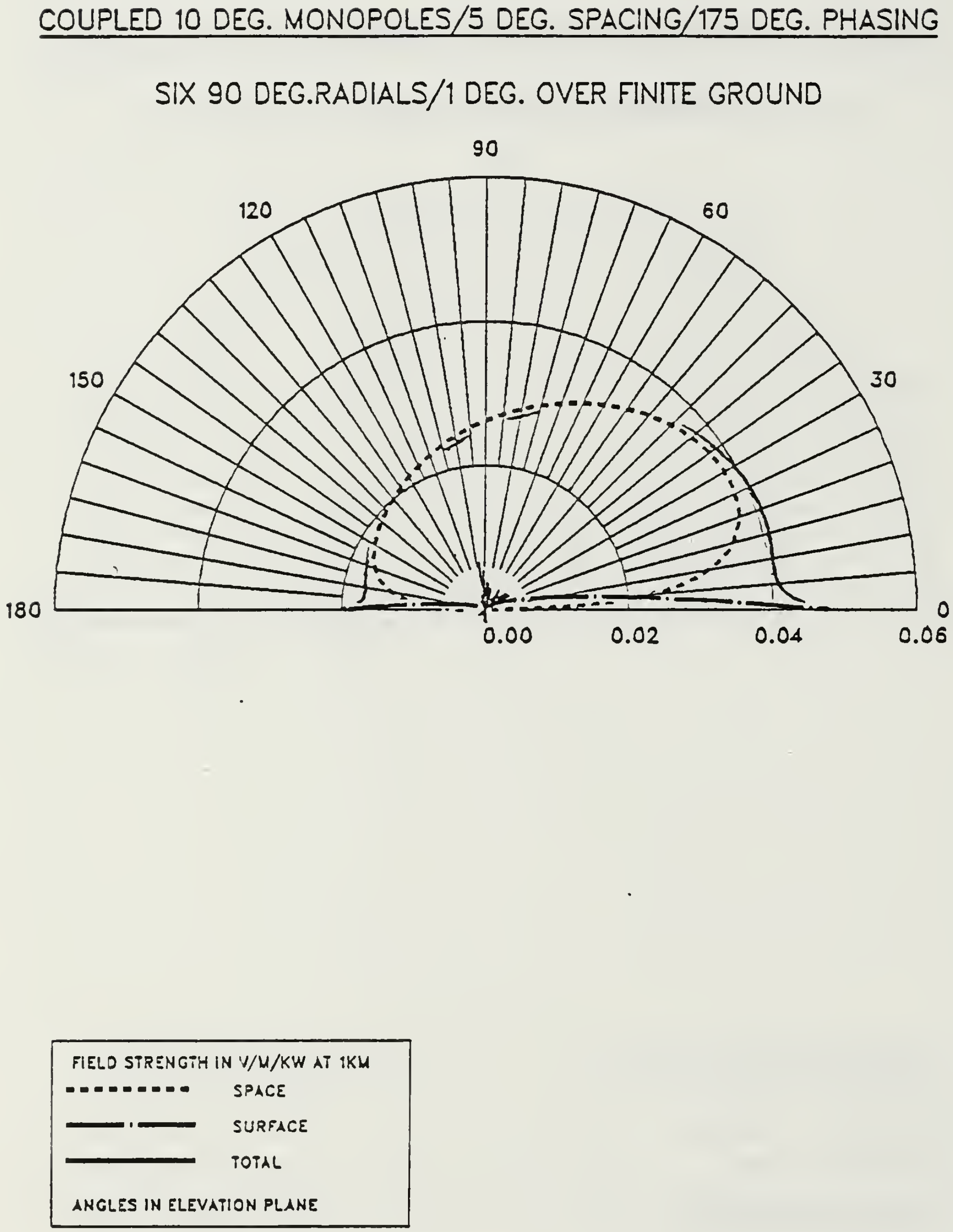


Figure A.61 Radiation Pattern - 10 Deg. Coupled Monopoles 1 Deg. over Finite Ground.

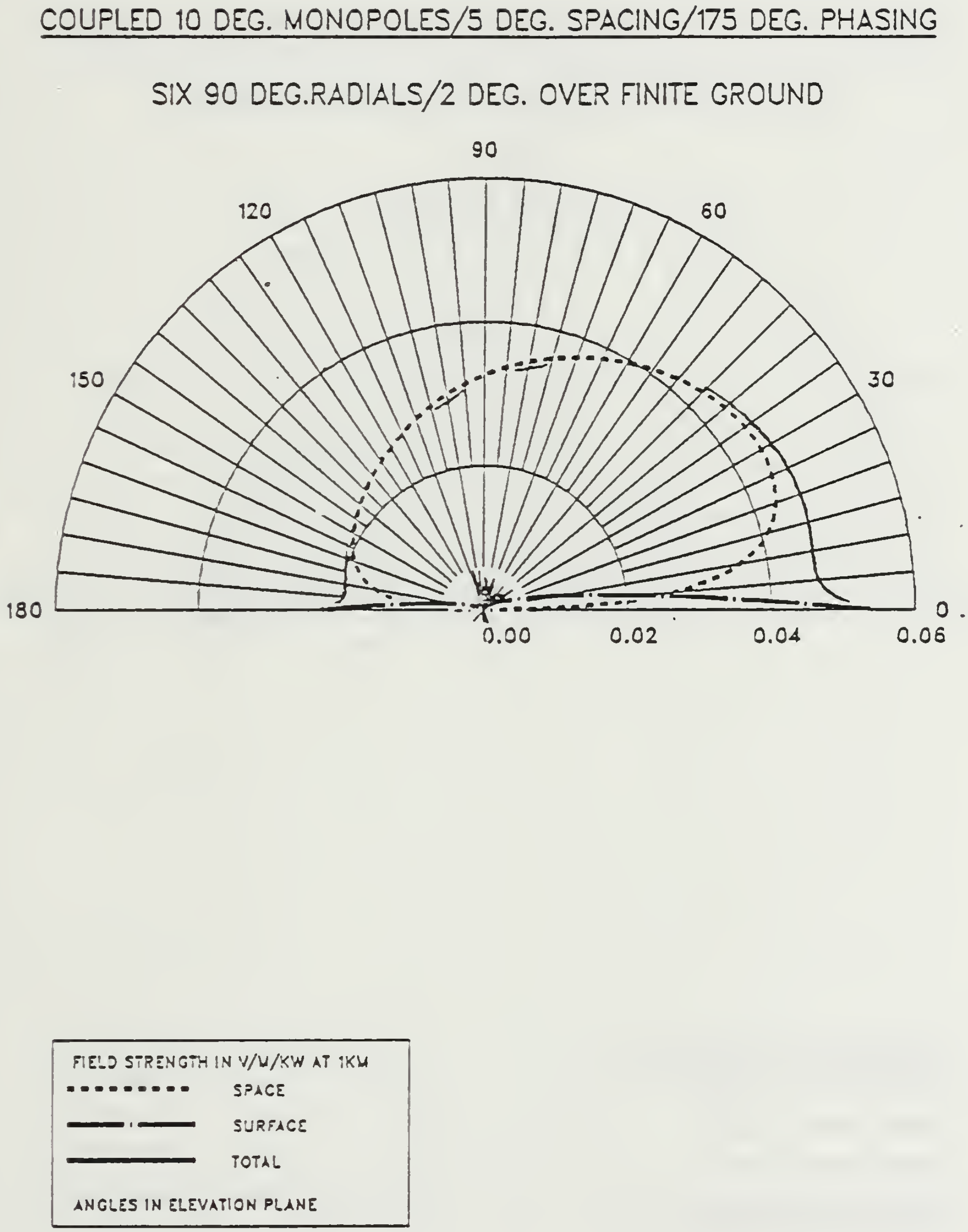


Figure A.62 Radiation Pattern - 10 Deg. Coupled Monopoles 2 Deg. over Finite Ground.

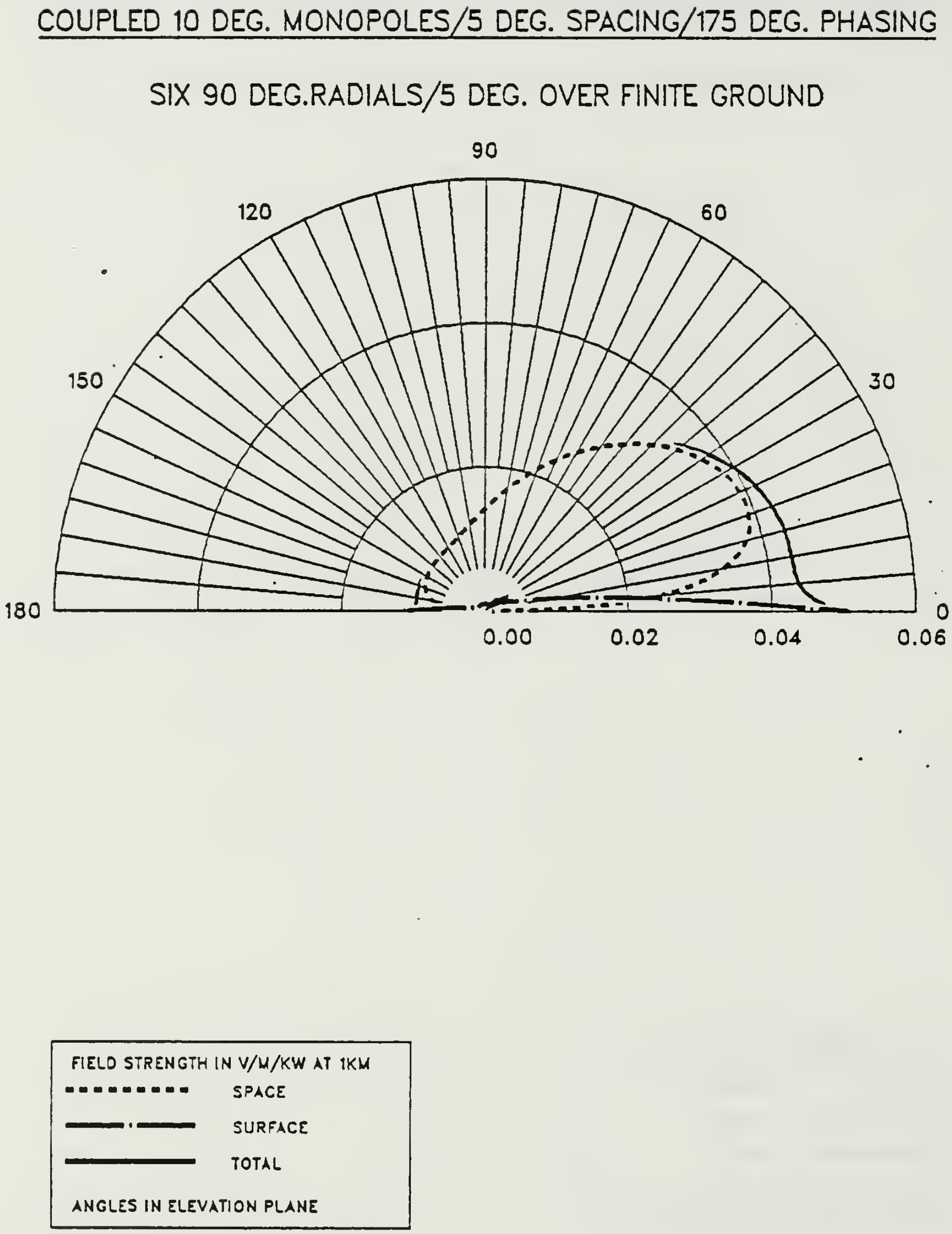


Figure A.63 Radiation Pattern - 10 Deg. Coupled Monopoles 5 Deg. over Finite Ground.

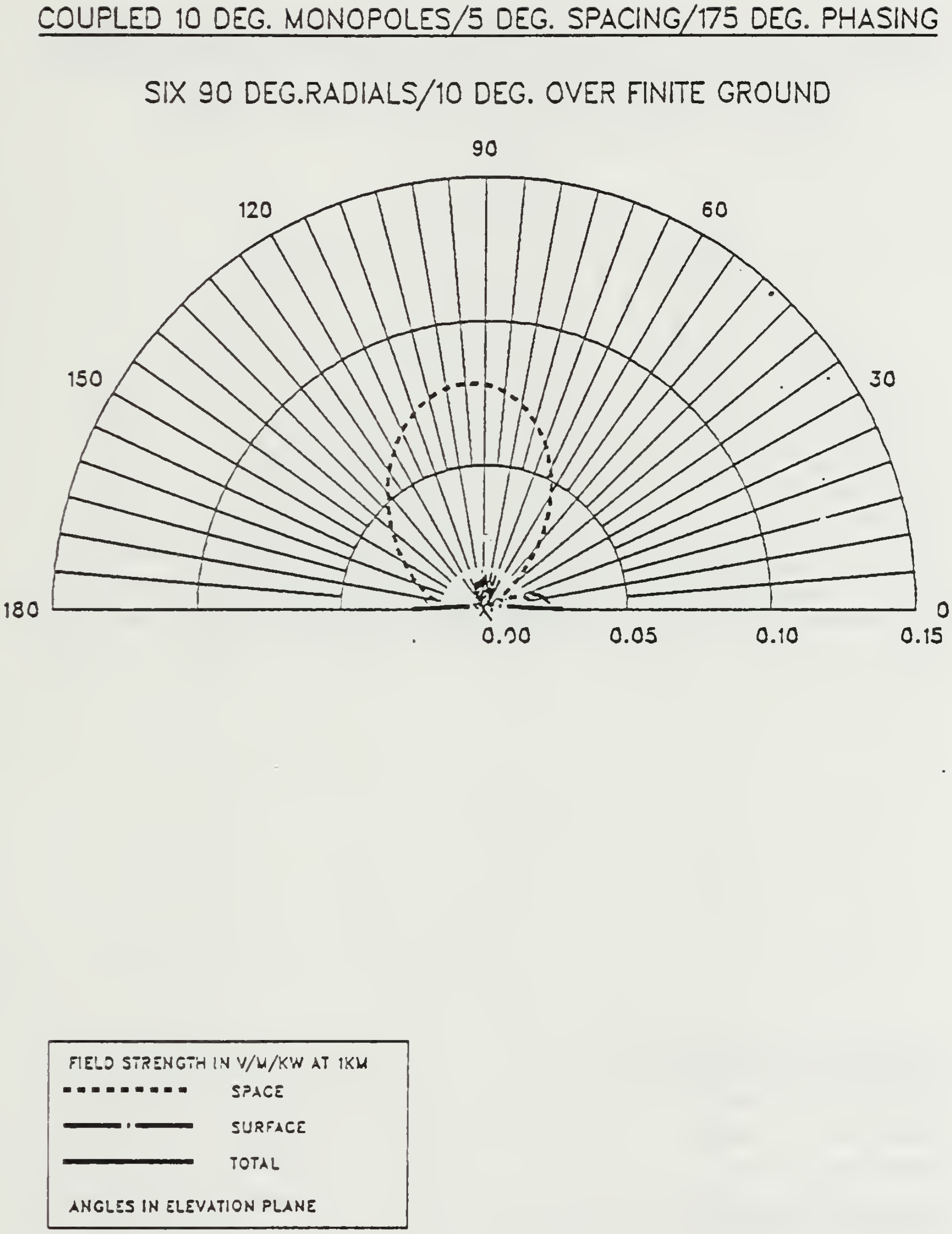


Figure A.64 Radiation Pattern - 10 Deg. Coupled Monopoles 10 Deg. over Finite Ground.

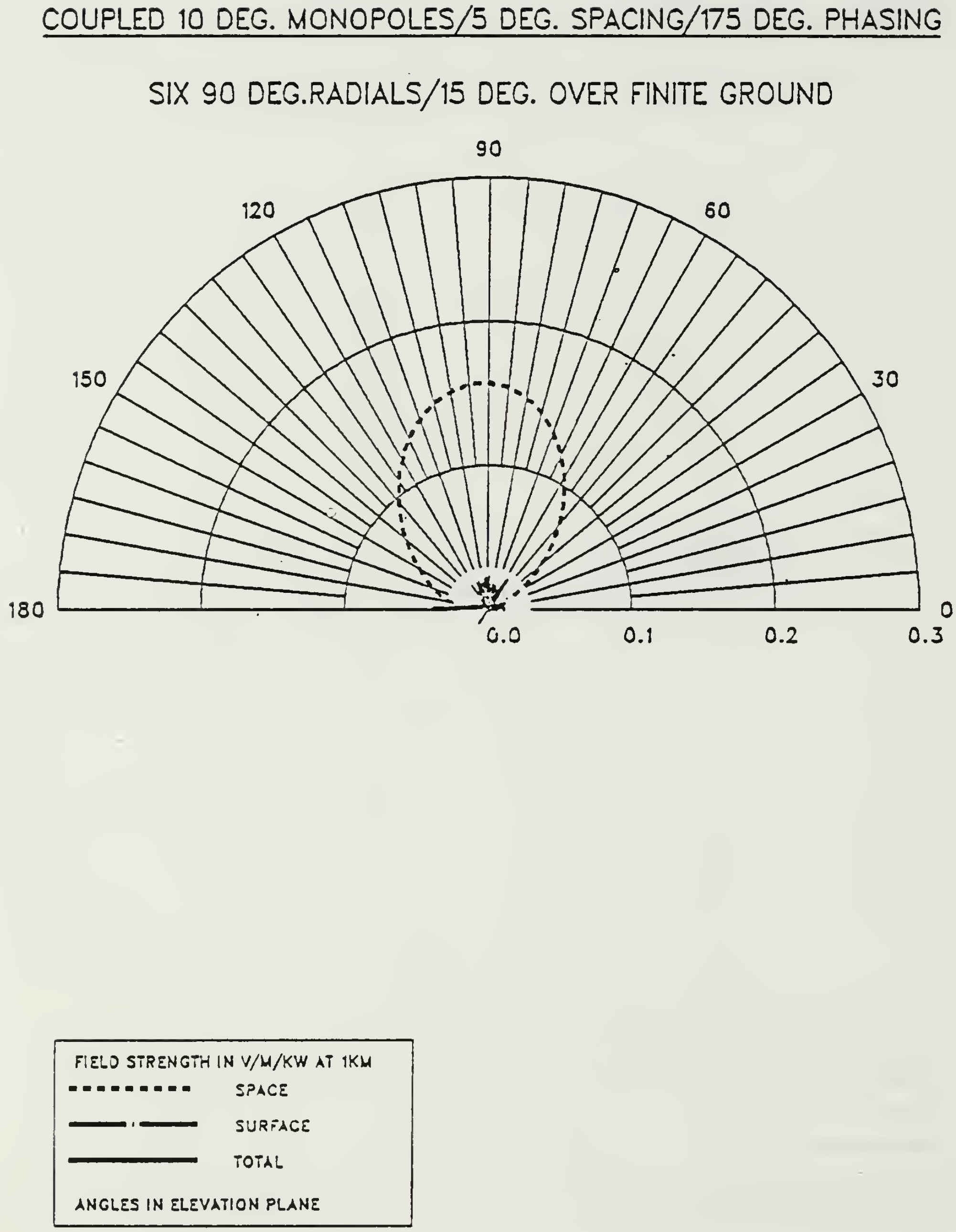


Figure A.65 Radiation Pattern - 10 Deg. Coupled Monopoles 15 Deg. over Finite Ground.

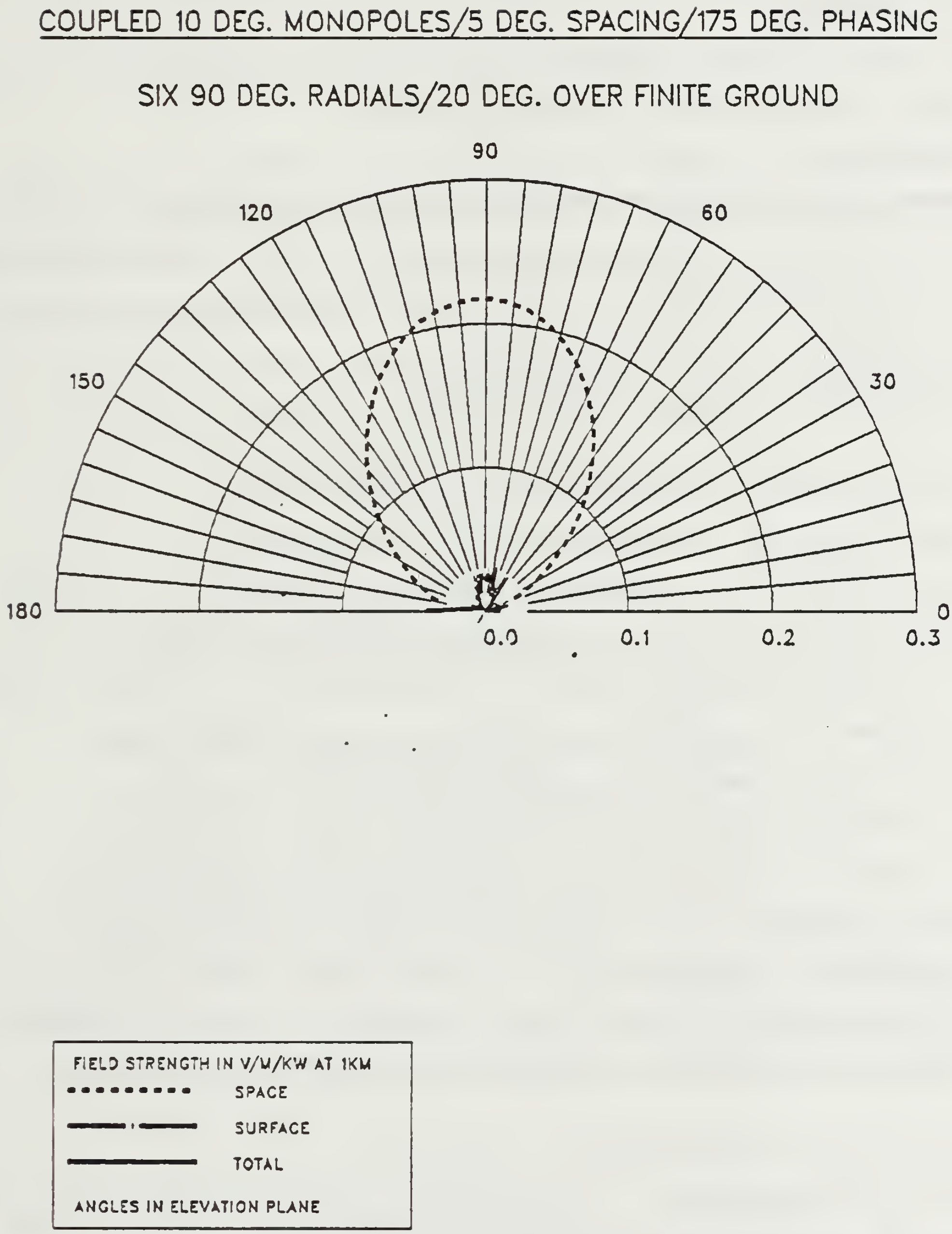


Figure A.66 Radiation Pattern - 10 Deg. Coupled Monopoles 20 Deg. over Finite Ground.

APPENDIX B
INPUT DATA SETS USED FOR THE COMPUTER MODELS

1.The following data set was used to model Biby's ASW antenna.

CM FILE MP5 DATA
CM DATA SET TO SIMULATE BIBY'S ASW ANTENNA (REF. BIBY'S FIGURE:7C)
CM 135 DEG. HI MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)120 RADIAL ELEMENTS GROUND SCREEN $\lambda_0/4$ LONG
CM 3)8 IN NO. 10 DEG. HI RING RADIATORS AT 5 DEG. FROM THE MONOPOLE
CM 4)PHASE DIFFERENCE FOR THE DRIVE CURRENTS = 180.0 DEGS.
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0;0,4, 0.05 135 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05 135 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0;0,16, 0.05 135 DEGREES HIGH MONOPOLE
GW 4,7, 0,0,16, 0,0,112.43, 0.05 135 DEGREES HIGH MONOPOLE
GR 0,8 TO MAKE BURRIED GROUND SCREEN WITH 120 RADIAL WIRES
GW 18,1, 0,4.164,-.457, 0,4.164,0, .05 UNDER GROUND RING WIRE
GW 19,1, 0,4.164,0, 0,4.164,1.0, .05 ABOVE GROUND RING WIRE
GW 20,1, 0,4.164,1.0, 0,4.164,3.5, .05 ABOVE GROUND RING WIRE
GW 21,1, 0,4.164,3.5, 0,4.164,8.3278, .05 ABOVE GROUND RING WIRE
GW 5,1, 0,0,0, 0,4.164,-.457, 0.05 GROUND SCREEN SLOPING WIRE
GW 6,1, 0,4.164,-.457, 0,12.164,-.457, 0.05 HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.164,-.457, 0,74.95,-.457, 0.05 HORIZONTAL GROUND SCREEN
GM 1,14, 0,0,3.0, 0,0,0, 005.007 TO MAKE A CELL WITH 15 RADIALS
GE -1
GN 2, 0, 0, 0, 15, .004 SOMMERFELD GROUND
FR 0,0,0,0, 1.00 FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8 (USED FOR DNECGSI RUN)
LD 4,20,1,1,1E8 (USED FOR DNECGSI RUN)
EX 0,2,1,0,8.72 MONOPOLE CURRENT DRIVE (USED FOR DNECGSI RUN)

EX 0,20,1,0,-7.32 RING CURRENT DRIVE (USED FOR DNECGSI RUN)
PL3,1,1 (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)
EX 0,2,1,0,-69.133,678.12 MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
EX 0,20,1,0,-38.046,12607 RING VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN

2.The following data set was used to model the typical AM broadcast antenna with 120 buried radial wires.

CM FILE MP2-2 DATA
CM 90 DEG. HI MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)120 RADIAL ELEMENTS GROUND SCREEN $\lambda_0/4$ LONG
CM 3)NO FENCE
CM 4)NO RING RADIATORS
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0,0,4, 0.05 90 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05 90 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05 90 DEGREES HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05 90 DEGREES HIGH MONOPOLE
GR 0,8 TO MAKE BURRIED GROUND SCREEN WITH 120 RADIAL WIRES
GW 5,1, 0,0,0, 0,4.167,-.457, 0.05 SLOPING WIRE FOR GROUND SCREEN
GW 6,1, 0,4.167,-.457, 0,12.167,-.457, 0.05 HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.167,-.457, 0,75,-.457, 0.05 HORIZONTAL GROUND SCREEN
GM 1,14, 0,0,3.0, 0,0,0, 005.007
GE -1
GN 2, 0, 0, 0, 15, .004 SOMMERFELD GROUND
FR 0,0,0,0, 1.00 FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8 (USED FOR DNECGSI RUN)
EX 0,2,1,0,5.0 MONOPOLE CURRENT DRIVE (USED FOR DNECGSI RUN)

PL3,1,1 (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)
EX 0,2,1,0,197.27,112.99 MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER S
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN

3.The following data set was used to model the typical AM broadcast antenna with 16 buried radial wires.

CM FILE MP2 DATA
CM 90 DEG. HI MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)16 RADIAL ELEMENTS GROUND SCREEN $\lambda_0/4$ LONG
CM 3)NO FENCE
CM 4)NO RING RADIATORS
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0,0,4, 0.05 90 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05 90 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05 90 DEGREES HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05 90 DEGREES HIGH MONOPOLE
GR 0,8 TO MAKE BURRIED GROUND SCREEN WITH 16 RADIAL WIRES
GW 5,1, 0,0,0, 0,4.167,-.457, 0.05 SLOPING WIRE FOR GROUND SCREEN
GW 6,1, 0,4.167,-.457, 0,12.167,-.457, 0.05 HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.167,-.457, 0,75,-.457, 0.05 HORIZONTAL GROUND SCREEN
GM 1,1, 0,0,22.5, 0,0,0, 005.007
GE -1
GN 2, 0, 0, 0, 15, .004 SOMMERFELD GROUND
FR 0,0,0,0, 1.00 FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8 (USED FOR DNECGSI RUN)
EX 0,2,1,0,5.0 MONOPOLE CURRENT DRIVE (USED FOR DNECGSI RUN)
PL3,1,1 (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)

EX 0,2,1,0,211.05,123.98 MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN

4.The following data set was used with a drive currents phase difference of 184.5 degrees while studying the effect of varying phase for the Biby's ASW antenna.

CM FILE MP3-27 DATA
CM 90 DEG. HI MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)16 RADIAL ELEMENTS GROUND SCREEN $\lambda_0/4$ LONG
CM 3)NO FENCE
CM 4)8 IN NO. 10 DEG. HIGH RING RADIATORS AT 5 DEG. FROM THE MONOPOLE
CM 5)PHASE DIFFERENCE FOR THE DRIVE CURRENTS = 184.5 DEGREES.
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0,0,4, 0.05 90 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05 90 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05 90 DEGREES HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05 90 DEGREES HIGH MONOPOLE
GR 0,8 TO MAKE BURRIED GROUND SCREEN WITH 16 RADIAL WIRES
GW 8,1, 0,4.167,-.457, 0,4.167,0, .05 UNDER GROUND PART OF THE RING
GW 9,1, 0,4.167,0, 0,4.167,1.0, .05 ABOVE GROUND PART OF THE RING
GW 10,1, 0,4.167,1.0, 0,4.167,3.5, .05 ABOVE GROUND PART OF THE RING
GW 11,1, 0,4.167,3.5, 0,4.167,8.333, .05 ABOVE GROUND PART OF THE RING
GW 5,1, 0,0,0, 0,4.167,-.457, 0.05 SLOPING WIRE FOR GROUND SCREEN
GW 6,1, 0,4.167,-.457, 0,12.167,-.457, 0.05 HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.167,-.457, 0,75,-.457, 0.05 HORIZONTAL GROUND SCREEN
GM 1,1, 0,0,22.5, 0,0,0, 005.007
GE -1
GN 2, 0, 0, 0, 15, .004 SOMMERFELD GROUND
FR 0,0,0,0, 1.00 FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8 (USED FOR DNECGSI RUN)

```
LD 4,10,1,1,1E8   (USED FOR DNECGSI RUN)
EX 0,2,1,0,5.0   MONOPOLE CURRENT DRIVE (USED FOR DNECGSI RUN)
EX 0,10,1,0,-2.8038,-0.22067   RING CURRENT DRIVE (USED FOR DNECGSI RUN)
PL3,1,1   (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)
EX 0,2,1,0,4.9262,330.192  MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
EX 0,10,1,0,-953.44,11752   RING VOLTAGE DRIVE FOR 1KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN
```

5.The following data set was used with the 90 degree long top hat while studying the effect of varying the length of the top hat on ring radiators for the Biby's ASW antenna.

```
CM FILE MP3-39 DATA
CM 90 DEGREES HIGH MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)16 RADIAL ELEMENTS GROUND SCREEN λ0/4 LONG
CM 3)NO FENCE
CM 4)8 IN NO. 10 DEG. HI RING RADIATORS AT 5 DEG. FROM THE MONOPOLE
CM   WITH THE TOP HAT λ/4 LONG.
CM 5)PHASE DIFFERENCE FOR THE DRIVE CURRENTS = 184.5 DEGREES.
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0,0,4, 0.05   90 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05   90 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05   90 DEGREES HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05   90 DEGREES HIGH MONOPOLE
GR 0,8   TO MAKE BURRIED GROUND SCREEN WITH 16 RADIAL WIRES
GW 8,1, 0,4.167,-.457, 0,4.167,0, .05   UNDER GROUND PART OF THE RING
GW 9,1, 0,4.167,0, 0,4.167,1.0, .05   ABOVE GROUND PART OF THE RING
GW 10,1, 0,4.167,1.0, 0,4.167,3.5, .05   ABOVE GROUND PART OF THE RING
GW 11,1, 0,4.167,3.5, 0,4.167,8.333, .05   ABOVE GROUND PART OF THE RING
```

```
GW 12,1, 0,4.167,8.333, 0,6.167,8.333, .05   TOP HAT FOR THE RING
GW 13,1, 0,6.167,8.333, 0,9.167,8.333, .05   TOP HAT FOR THE RING
GW 14,1, 0,9.167,8.333, 0,13.167,8.333, .05   TOP HAT FOR THE RING
GW 15,9, 0,13.167,8.333, 0,79.167,8.333, .05   TOP HAT FOR THE RING
GW 5,1, 0,0,0, 0,4.167,-.457, 0.05   SLOPING WIRE FOR THE GROUND SCREEN
GW 6,1, 0,4.167,-.457, 0,12.167,-.457, 0.05   HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.167,-.457, 0,75,-.457, 0.05   HORIZONTAL GROUND SCREEN
GM 1,1, 0,0,22.5, 0,0,0, 005.007
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8   (USED FOR DNECGSI RUN)
LD 4,10,1,1,1E8   (USED FOR DNECGSI RUN)
EX 0,2,1,0,5.0   MONOPOLE CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,10,1,0,-2.4923,-0.19615   RING CURRENT DRIVE (FOR DNECGSI RUN)
PL3,1,1   (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)
EX 0,2,1,0,4.8466,-499.87   MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
EX 0,10,1,0,-16.447,-392.29   RING VOLTAGE DRIVE FOR 1KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN
```

6.The following data set was used with the 10 degree fence while studying the effect of varying the fence height for the Biby's ASW antenna.

CM FILE MP3-37 DATA
CM 90 DEGREES HIGH MONOPOLE AT ORIGIN WITH:
CM 1)SOMMERFELD GROUND (ε = 15 F/M, σ = .004 S/M, f = 1.0 MHZ)
CM 2)16 RADIAL ELEMENTS GROUND SCREEN $\lambda_0/4$ LONG
CM 3)10 DEG. HIGH FENCE AT $\lambda_0/4$ DISTANCE AWAY FROM THE MONOPOLE.
CM 4)8 IN NO. 10 DEG. HI RING RADIATORS AT 5 DEG. FROM THE MONOPOLE
CM   WITH THE 80 DEG. LONG TOP HAT.
CM 5)PHASE DIFFERENCE FOR THE DRIVE CURRENTS = 180.0 DEGREES.
CM USE NECGS TO RUN THE DATA SET

```
CM USE PLOTRPVS TO PLOT THE E FIELD.
CE
GW 1,1, 0,0,0, 0,0,4, 0.05   90 DEGREES HIGH MONOPOLE
GW 2,1, 0,0,4, 0,0,8, 0.05   90 DEGREES HIGH MONOPOLE
GW 3,1, 0,0,8, 0,0,16, 0.05   90 DEGREES HIGH MONOPOLE
GW 4,4, 0,0,16, 0,0,75, 0.05   90 DEGREES HIGH MONOPOLE
GW 8,1, 0,4.167,-.457, 0,4.167,0, .05   UNDER GROUND PART OF THE RING
GR 0,8   TO MAKE BURRIED GROUND SCREEN WITH 16 RADIAL WIRES
GW 18,1, 0,4.167,-.457, 0,4.167,0, .05   UNDER GROUND PART OF THE RING
GW 19,1, 0,4.167,0, 0,4.167,1.0, .05   ABOVE GROUND PART OF THE RING
GW 20,1, 0,4.167,1.0, 0,4.167,3.5, .05   ABOVE GROUND PART OF THE RING
GW 21,1, 0,4.167,3.5, 0,4.167,8.333, .05   ABOVE GROUND PART OF THE RING
GW 22,1, 0,4.167,8.333, 0,6.167,8.333, .05   TOP HAT FOR THE RING
GW 23,1, 0,6.167,8.333, 0,9.167,8.333, .05   TOP HAT FOR THE RING
GW 24,15, 0,9.167,8.333, 0,66.66,8.333, .05   TOP HAT FOR THE RING
GW 5,1, 0,0,0, 0,4.167,-.457, 0.05   SLOPING WIRE FOR THE GROUND SCREEN
GW 6,1, 0,4.167,-.457, 0,12.167,-.457, 0.05   HORIZONTAL GROUND SCREEN
GW 7,4, 0,12.167,-.457, 0,75,-.457, 0.05   HORIZONTAL GROUND SCREEN
GW 8,1, 0,75,-.457, 0,75,0, .05   UNDER GROUND WIRE FOR THE FENCE
GW 9,1, 0,75,0, 0,75,1, .05   OVER GROUND WIRE FOR THE FENCE
GW 10,1, 0,75,1, 0,75,3.5, .05   OVER GROUND WIRE FOR THE FENCE
GW 11,1, 0,75,3.5, 0,75,8.333, .05   OVER GROUND WIRE FOR THE FENCE
GW 12,1, 0,75,1, -2.5,75,1, .05   OVER GROUND WIRE FOR THE FENCE
GW 13,1, -2.5,75,1, -2.5,75,3.5, .05   OVER GROUND WIRE FOR THE FENCE
GW 14,1, -2.5,75,3.5, -2.5,75,8.333, .05   OVER GROUND WIRE FOR THE FENCE
GW 15,1, 0,75,1, 2.5,75,1, .05   OVER GROUND WIRE FOR THE FENCE
GW 16,1, 2.5,75,1, 2.5,75,3.5, .05   OVER GROUND WIRE FOR THE FENCE
GW 17,1, 2.5,75,3.5, 2.5,75,8.333, .05   OVER GROUND WIRE FOR THE FENCE
GM 1,1, 0,0,22.5, 0,0.0, 005.017
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,2,1,1,1E8   (USED FOR DNECGSI RUN)
LD 4,10,1,1,1E8   (USED FOR DNECGSI RUN)
EX 0,2,1,0,5.0   MONOPOLE CURRENT DRIVE (FOR DNECGSI RUN)
```

EX 0,20,1,0,-2.0313,0 RING CURRENT DRIVE (FOR DNECGSI RUN)
PL3,1,1 (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04 (USED FOR DNECGSI RUN)
EX 0,2,1,0,35.735,-441.25 MONOPOLE VOLTAGE DRIVE FOR 1KW PEAK I/P POWER
EX 0,20,1,0,-31.245,-81.429 RING VOLTAGE DRIVE FOR 1KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS'. (USED FOR DNECGS RUN)
EN

7.The following data set was used with the isolated 180 deg. dipole in free space while doing the generic radiator study.

CM FILE GFS1 DATA
CM ISOLATED 180 DEGREE DIPOLE IN FREE SPACE
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GW 1,59, 0,0,0, 0,0,149.9, 0.05 180 DEG. DIPOLE
GE
FR 0,0,0,0, 1.00 FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,30,30,1E8 (USED FOR DNECGSI RUN)
EX 0,1,30,0,5 CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1 (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000 (USED FOR DNECGSI RUN)
EX 0,1,30.0,284.72,164.99 VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1 (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0. 1000 (USED FOR DNECGS RUN)
EN

8.The following data set was used with the isolated 180 deg. dipole over perfect ground while doing the generic radiator study.

CM FILE GPG1 DATA
CM ISOLATED 180 DEGREE DIPOLE OVER PERFECT GROUND

```
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GW 1,59, 0,0,0, 0,0,149.9, 0.05   180 DEG. DIPOLE
GE 1
GN 1
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,30,30,1E8   (USED FOR DNECGSI RUN)
EX 0,1,30,0,5   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,30,0,1674.8,-1530.0   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0, 1000   (USED FOR DNECGS RUN)
EN
```

9.The following data set was used with the isolated 180 deg. dipole over finite ground while doing the generic radiator study.

```
CM FILE GFG1 DATA
CM ISOLATED 180 DEGREE DIPOLE OVER FINITE GROUND
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,59, 0,0,0, 0,0,149.9, 0.05   180 DEG. DIPOLE
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,30,30,1E8   (USED FOR DNECGSI RUN)
EX 0,1,30,0,5   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04   (USED FOR DNECGSI RUN)
EX 0,1,30,0,347.86,205.44   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (FOR DNECGS RUN)
EN
```

10.The following data set was used with the isolated 180 deg. dipole 0.5 deg. over finite ground while doing the generic radiator study.

```
CM FILE GFG1-1 DATA
CM ISOLATED 180 DEGREE DIPOLE 0.5 DEG. OVER FINITE GROUND
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,59, 0,0,.41639, 0,0,150.31679, 0.05   180 DEG. DIPOLE
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,30,30,1E8   (USED FOR DNECGSI RUN)
EX 0,1,30,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04   (USED FOR DNECGSI RUN)
EX 0,1,30,0,343.57,188.82   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (FOR DNECGS RUN)
EN
```

11.The following data set was used with the coupled 20 deg. dipoles in free space while doing the generic radiator study.

```
CM FILE GFS7 DATA
CM COUPLED 20 DEG. DIPOLES IN FREE SPACE
CM 5 DEG. SPACING/175 DEG. PHASING
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GR 0,1
GW 1,7, 2.08194,0,0, 2.08194,0,16.656, 0.05   20 DEG. DIPOLE
GW 2,7, -2.08194,0,0, -2.08194,0,16.656, 0.05   20 DEG. DIPOLE
```

```
GE
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,4,4,1E8   (USED FOR DNECGSI RUN)
LD 4,2,4,4,1E8   (USED FOR DNECGSI RUN)
EX 0,1,4,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,4,0,-0.99620,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,4,0,7611.3,-1001298.6   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,4,0,94801.81,996879.1   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0, 1000   (USED FOR DNECGS RUN)
EN
```

12.The following data set was used with the coupled 20 deg. dipoles over perfect ground while doing the generic radiator study.

```
CM FILE GPG7 DATA
CM COUPLED 20 DEG. DIPOLES OVER PERFECT GROUND
CM 5 DEG. SPACING/175 DEG. PHASING
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GR 0,1
GW 1,7, 2.08194,0,0, 2.08194,0,16.656, 0.05   20 DEG. DIPOLE
GW 2,7, -2.08194,0,0, -2.08194,0,16.656, 0.05   20 DEG. DIPOLE
GE -1
GN 1
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,4,4,1E8   (USED FOR DNECGSI RUN)
LD 4,2.4,4,1E8   (USED FOR DNECGSI RUN)
EX 0,1,4,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,4,0,-0.99620,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
```

```
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,4,0,4066.2,-698038    VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,4,0,64855,695082   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0.-1,0, 1000   (USED FOR DNECGS RUN)
EN
```

13.The following data set was used with the coupled 20 deg. dipoles over finite ground while doing the generic radiator study.

```
CM FILE GFG7 DATA
CM COUPLED 20 DEG. DIPOLES OVER FINITE GROUND
CM 5 DEG. SPACING/175 DEG. PHASING
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GR 0,1
GW 1,7, 2.08194,0,0, 2.08194,0,16.656, 0.05   20 DEG. DIPOLE
GW 2,7, -2.08194,0,0, -2.08194,0,16.656, 0.05   20 DEG. DIPOLE
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,4,4,1E8   (USED FOR DNECGSI RUN)
LD 4,2,4,4,1E8   (USED FOR DNECGSI RUN)
EX 0,1,4,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2.4,0,-0.99620,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,4,0,249.55,-36585    VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,4,0,3361.6,36440   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

14.The following data set was used with the coupled 20 deg. dipoles 0.5 deg. over finite ground while doing the generic radiator study.

```
CM FILE GFG7-1 DATA
CM COUPLED 20 DEG. DIPOLES 0.5 DEG. OVER FINITE GROUND
CM 5 DEG. SPACING/175 DEG. PHASING
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GR 0,1
GW 1,7, 2.08194,0,.41639, 2.08194,0,17.07199, 0.05   20 DEG. DIPOLE
GW 2,7, -2.08194,0,.41639, -2.08194,0,17.07199, 0.05   20 DEG. DIPOLE
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,4,4,1E8   (USED FOR DNECGSI RUN)
LD 4,2,4,4,1E8   (USED FOR DNECGSI RUN)
EX 0,1,4,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,4,0,-0.99620,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,4,0,349.48,-54165    VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,4,0,5016.0,53947   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

15.The following data set was used with the isolated 90 deg. monopole in free space while doing the generic radiator study.

```
CM FILE GFS8 DATA
CM ISOLATED 90 DEG. MONOPOLE IN FREE SPACE
CM FOUR 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
```

```
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GW 1,30, 0,0,.1, 0,0,75.05, 0.05   90 DEG. MONOPOLE
GR 0,4   TO MAKE 4 RADIALS
GW 2,30, 0,0,.1, 74.95,0,.1, 0.05   90 DEG. LONG RADIAL
GE 0
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,150.32,28.613   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1.0, 1000   (USED FOR DNECGS RUN)
EN
```

16.The following data set was used with the isolated 90 deg. monopole over perfect ground while doing the generic radiator study.

```
CM FILE GPG8 DATA
CM ISOLATED 90 DEG. MONOPOLE OVER PERFECT GROUND
CM FOUR 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GW 1,30, 0,0,.1, 0.0,75.05, 0.05   90 DEG. MONOPOLE
GR 0,4   TO MAKE 4 RADIALS
GW 2,30, 0,0,.1, 74.95,0,.1, 0.05   90 DEG. LONG RADIAL
GE -1
GN 1
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
```

```
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,200.46,111.14   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0, 1000   (USED FOR DNECGS RUN)
EN
```

17.The following data set was used with the isolated 90 deg. monopole over finite ground while doing the generic radiator study.

```
CM FILE GFG8 DATA
CM ISOLATED 90 DEG. MONOPOLE OVER FINITE GROUND
CM FOUR 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,30, 0,0,.1, 0,0,75.05, 0.05   90 DEG. MONOPOLE
GR 0,4   TO MAKE 4 RADIALS
GW 2,30, 0,0,.1, 74.95,0,.1, 0.05   90 DEG. LONG RADIAL
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,449.29,198.35   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

18.The following data set was used with the isolated 90 deg. monopole 0.5 deg. over finite ground while doing the generic radiator study.

```
CM FILE GFG8-1 DATA
CM ISOLATED 90 DEG. MONOPOLE 0.5 DEG. OVER FINITE GROUND
CM FOUR 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NECGS TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,30, 0,0,.41639, 0,0,75.36659, 0.05   90 DEG. MONOPOLE
GR 0,4   TO MAKE 4 RADIALS
GW 2,30, 0,0,.41639, 74.9502,0,.41639, 0.05   90 DEG. LONG RADIAL
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,218.06,218.14   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

19.The following data set was used with the coupled 10 deg. monopoles in free space while doing the generic radiator study.

```
CM FILE GFS11 DATA
CM COUPLED 10 DEG. MONOPOLES IN FREE SPACE
CM SIX 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NPGNEC TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
```

```
GW 1,5, 2.08195,0,.1, 2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 2,5, -2.08195,0,.1, -2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 3,1, 0,0,.1, 2.08195,0,.1, .05   RADIAL/+X
GW 4,29, 4.1639,0,.1, 77.0322,0,.1, .05   RADIAL/+X
GW 5,1, 0,0,.1, -2.08195,0,.1, .05   RADIAL/-X
GW 6,29, -4.1639,0,.1, -77.0322,0,.1, .05   RADIAL/-X
GW 7,1, 2.08195,0,.1, 2.08195,2.08195,.1, .05   RADIAL/+Y/TAG1
GW 8,29, 2.08195,2.08195,.1, 2.08195,74.95,.1, .05   RADIAL/+Y/TAG1
GW 9,1, 2.08195,0,.1, 2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG1
GW 10,29, 2.08195,-2.08195,.1, 2.08195,-74.95,.1, .05   RADIAL/-Y/TAG1
GW 11,1, -2.08195,0,.1, -2.08195,2.08195,.1, .05   RADIAL/+Y/TAG2
GW 12,29, -2.08195,2.08195,.1, -2.08195,74.95,.1, .05   RADIAL/+Y/TAG2
GW 13,1, -2.08195,0,.1, -2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG2
GW 14,29, -2.08195,-2.08195,.1, -2.08195,-74.95,.1, .05   RADIAL/-Y/TAG2
GW 15,1, 2.08195,0,.1, 4.1639,0,.1, .05  SPLICE FOR EQ. LN. NR. FEED
GW 16,1, -2.08195,0,.1, -4.1639,0,.1, .05   SPLICE FOR EQ. LN. NR. FEED
GE 0
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
LD 4,2,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,2,0,-.99619,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,709.98,-74384   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,2,0,7161.9,74043   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0, 1000   (USED FOR DNECGS RUN)
EN
```

20.The following data set was used with the coupled 10 deg. monopoles over perfect ground while doing the generic radiator study.

```
CM FILE GPG11 DATA
```

```
CM COUPLED 10 DEG. MONOPOLES OVER PERFECT GROUND
CM SIX 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NPGNEC TO RUN THE DATA SET
CM USE PLOTVNAB TO PLOT THE E FIELD
CE
GW 1,5, 2.08195,0,.1, 2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 2,5, -2.08195,0,.1, -2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 3,1, 0,0,.1, 2.08195,0,.1, .05   RADIAL/+X
GW 4,29, 4.1639,0,.1, 77.0322,0,.1, .05   RADIAL/+X
GW 5,1, 0,0,.1, -2.08195,0,.1, .05   RADIAL/-X
GW 6,29, -4.1639,0,.1, -77.0322,0,.1, .05   RADIAL/-X
GW 7,1, 2.08195,0,.1, 2.08195,2.08195,.1, .05   RADIAL/+Y/TAG1
GW 8,29, 2.08195,2.08195,.1, 2.08195,74.95,.1, .05   RADIAL/+Y/TAG1
GW 9,1, 2.08195,0,.1, 2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG1
GW 10,29, 2.08195,-2.08195,.1, 2.08195,-74.95,.1, .05   RADIAL/-Y/TAG1
GW 11,1, -2.08195,0,.1, -2.08195,2.08195,.1, .05   RADIAL/+Y/TAG2
GW 12,29, -2.08195,2.08195,.1, -2.08195,74.95,.1, .05   RADIAL/+Y/TAG2
GW 13,1, -2.08195,0,.1, -2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG2
GW 14,29, -2.08195,-2.08195,.1, -2.08195,-74.95,.1, .05   RADIAL/-Y/TAG2
GW 15,1, 2.08195,0,.1, 4.1639,0,.1, .05  SPLICE FOR EQ. LN. NR. FEED
GW 16,1, -2.08195,0,.1, -4.1639,0,.1, .05   SPLICE FOR EQ. LN. NR. FEED
GE -1
GN 1
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
LD 4,2,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,2,0,-.99619..08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,6702.5,-816419   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,2,0,77809,812785   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PL 3,1,1   (USED FOR DNECGS RUN)
RP 0,181,1,1000, 90,0,-1,0, 1000   (USED FOR DNECGS RUN)
```

EN

21.The following data set was used with the coupled 10 deg. monopoles over finite ground while doing the generic radiator study.

```
CM FILE GFG11 DATA
CM COUPLED 10 DEG. MONOPOLES OVER FINITE GROUND
CM SIX 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NPGNEC TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,5, 2.08195,0,.1, 2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 2,5, -2.08195,0,.1, -2.08195,0,8.4278, 0.05   10 DEG. MONOPOLE
GW 3,1, 0,0,.1, 2.08195,0,.1, .05   RADIAL/+X
GW 4,29, 4.1639,0,.1, 77.0322,0,.1, .05   RADIAL/+X
GW 5,1, 0,0,.1, -2.08195,0,.1, .05   RADIAL/-X
GW 6,29, -4.1639,0,.1, -77.0322,0,.1, .05   RADIAL/-X
GW 7,1, 2.08195,0,.1, 2.08195,2.08195,.1, .05   RADIAL/+Y/TAG1
GW 8,29, 2.08195,2.08195,.1, 2.08195,74.95,.1, .05   RADIAL/+Y/TAG1
GW 9,1, 2.08195,0,.1, 2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG1
GW 10,29, 2.08195,-2.08195,.1, 2.08195,-74.95,.1, .05   RADIAL/-Y/TAG1
GW 11,1, -2.08195,0,.1, -2.08195,2.08195,.1, .05   RADIAL/+Y/TAG2
GW 12,29, -2.08195,2.08195,.1, -2.08195,74.95,.1, .05   RADIAL/+Y/TAG2
GW 13,1, -2.08195,0,.1, -2.08195,-2.08195,.1, .05   RADIAL/-Y/TAG2
GW 14,29, -2.08195,-2.08195,.1, -2.08195,-74.95,.1, .05   RADIAL/-Y/TAG2
GW 15,1, 2.08195,0,.1, 4.1639,0,.1, .05  SPLICE FOR EQ. LN. NR. FEED
GW 16,1, -2.08195,0,.1, -4.1639,0,.1, .05   SPLICE FOR EQ. LN. NR. FEED
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
LD 4,2,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
```

```
EX 0,2,2,0,-.99619,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,267.64,-22599   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,2,0,2166.6.22673   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

22.The following data set was used with the coupled 10 deg. monopoles 0.5 deg. over finite ground while doing the generic radiator study.

```
CM FILE GFG11-1 DATA
CM COUPLED 10 DEG. MONOPOLES 0.5 DEG. OVER FINITE GROUND
CM SIX 90 DEG. RADIALS
CM STRUCTURE 2 RADII ABOVE X-Y PLANE
CM USE NPGNEC TO RUN THE DATA SET
CM USE PLOTRPVS TO PLOT THE E FIELD
CE
GW 1,5, 2.08195,0,.41639, 2.08195,0,8.74419, 0.05   10 DEG. MONOPOLE
GW 2,5, -2.08195.0,.41639, -2.08195,0,8.74419, 0.05   10 DEG. MONOPOLE
GW 3,1, 0,0,.41639, 2.08195,0,.41639, .05   RADIAL/+X
GW 4,29, 4.1639,0,.41639, 77.0322,0,.41639, .05   RADIAL/+X
GW 5,1, 0,0,.41639, -2.08195,0,.41639, .05   RADIAL/-X
GW 6,29, -4.1639,0,.41639, -77.0322,0,.41639, .05   RADIAL/-X
GW 7,1, 2.08195,0,.41639, 2.08195,2.08195,.41639, .05   RADIAL/+Y/TAG1
GW 8,29, 2.08195,2.08195,.41639, 2.08195,74.95,.41639, .05  RADIAL/+Y/TAG1
GW 9,1, 2.08195,0,.41639, 2.08195,-2.08195,.41639, .05   RADIAL/-Y/TAG1
GW 10,29, 2.08195,-2.08195,.41639, 2.08195,-74.95,.41639, .05   RADIAL/-Y/TAG1
GW 11,1, -2.08195,0,.41639, -2.08195,2.08195,.41639, .05   RADIAL/+Y/TAG2
GW 12,29, -2.08195,2.08195,.41639, -2.08195,74.95,.41639, .05   RADIAL/+Y/TAG2
GW 13,1, -2.08195,0,.41639, -2.08195,-2.08195,.41639, .05   RADIAL/-Y/TAG2
GW 14,29, -2.08195,-2.08195,.41639, -2.08195,-74.95,.41639, .05   RADIAL/-Y/TAG2
GW 15,1, 2.08195,0,.41639, 4.1639,0,.41639, .05  SPLICE FOR EQ. LN. NR. FEED
GW 16,1, -2.08195,0,.41639, -4.1639,0,.41639, .05   SPLICE FOR EQ. LN. NR. FEED
```

```
GE -1
GN 2, 0, 0, 0, 15, .004   SOMMERFELD GROUND
FR 0,0,0,0, 1.00   FREQUENCY = 1000 KHZ (AT 1000 KHZ 1 DEG. = 0.83278 M)
LD 4,1,2,2,1E8   (USED FOR DNECGSI RUN)
LD 4,2,2,2,1E8   (USED FOR DNECGSI RUN)
EX 0,1,2,0,1   CURRENT DRIVE (FOR DNECGSI RUN)
EX 0,2,2,0,-.99619,.08716   CURRENT DRIVE (FOR DNECGSI RUN)
PL 3,1,1   (USED FOR DNECGSI RUN)
RP 0,1,1,1000, 90,0,0,0, 1000   (USED FOR DNECGSI RUN)
EX 0,1,2,0,388.89,-48037   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
EX 0,2,2,0,4538.7,47893   VOLTAGE DRIVE FOR 1 KW PEAK INPUT POWER
PLUS PL3,RP CARDS FROM FILE 'NECGS RPCARDS' (USED FOR DNECGS RUN)
EN
```

23.The following is a listing of file "NECGS RPCARDS" used as a part of all the data sets which model a structure over finite ground and are required to output the spacewave E field (PL3, RP0 cards), and the groundwave E field added to the spacewave E field (PL3, RP1 cards). Fortran code RP1 MAKER was Used to produce PL3, RP1 cards.

```
PL 3,1,1
RP 0,90,1,1000, 90,180,-1,0, 1000
PL 3,1,1
RP 0,91,1,1000, 0,0,1,0, 1000
PL3,1,1
RP1,1,1,1000,0.000E+00,0.180E+03,0.,0.,0.100E+04
PL3,1,1
RP1,1,1,1000,0.175E+02,0.180E+03,0.,0.,0.100E+04
PL3,1,1
RP1,1,1,1000,0.349E+02,0.180E+03,0.,0.,0.999E+03
PL3,1,1
RP1,1,1,1000,0.523E+02,0.180E+03,0.,0.,0.999E+03
PL3,1,1
RP1,1,1,1000,0.698E+02,0.180E+03,0.,0.,0.998E+03
```

```
PL3,1,1
RP1,1,1,1000,0.872E+02,0.180E+03,0.,0.,0.996E+03
PL3,1,1
RP1,1,1,1000,0.105E+03,0.180E+03,0.,0.,0.995E+03
PL3,1,1
RP1,1,1,1000,0.122E+03,0.180E+03,0.,0.,0.993E+03
PL3,1,1
RP1,1,1,1000,0.139E+03,0.180E+03,0.,0.,0.990E+03
PL3,1,1
RP1,1,1,1000,0.156E+03,0.180E+03,0.,0.,0.988E+03
PL3,1,1
RP1,1,1,1000,0.174E+03,0.180E+03,0.,0.,0.985E+03
PL3,1,1
RP1,1,1,1000,0.191E+03,0.180E+03,0.,0.,0.982E+03
PL3,1,1
RP1,1,1,1000,0.208E+03,0.180E+03,0.,0.,0.978E+03
PL3,1,1
RP1,1,1,1000,0.225E+03,0.180E+03,0.,0.,0.974E+03
PL3,1,1
RP1,1,1,1000,0.242E+03,0.180E+03,0.,0.,0.970E+03
PL3,1,1
RP1,1,1,1000,0.259E+03,0.180E+03,0.,0.,0.966E+03
PL3,1,1
RP1,1,1,1000,0.276E+03,0.180E+03,0.,0.,0.961E+03
PL3,1,1
RP1,1,1,1000,0.292E+03,0.180E+03,0.,0.,0.956E+03
PL3,1,1
RP1,1,1,1000,0.309E+03,0.180E+03,0.,0.,0.951E+03
PL3,1,1
RP1,1,1,1000,0.326E+03,0.180E+03,0.,0.,0.946E+03
PL3,1,1
RP1,1,1,1000,0.342E+03,0.180E+03,0.,0.,0.940E+03
PL3,1,1
RP1,1,1,1000,0.358E+03,0.180E+03,0.,0.,0.934E+03
PL3,1,1
```

```
RP1,1,1,1000,0.375E+03,0.180E+03,0.,0.,0.927E+03
PL3,1,1
RP1,1,1,1000,0.391E+03,0.180E+03,0.,0.,0.921E+03
PL3,1,1
RP1,1,1,1000,0.407E+03,0.180E+03,0.,0.,0.914E+03
PL3,1,1
RP1,1,1,1000,0.423E+03,0.180E+03,0.,0.,0.906E+03
PL3,1,1
RP1,1,1,1000,0.438E+03,0.180E+03,0.,0.,0.899E+03
PL3,1,1
RP1,1,1,1000,0.454E+03,0.180E+03,0.,0.,0.891E+03
PL3,1,1
RP1,1,1,1000,0.469E+03,0.180E+03,0.,0.,0.883E+03
PL3,1,1
RP1,1,1,1000,0.485E+03,0.180E+03,0.,0.,0.875E+03
PL3,1,1
RP1,1,1,1000,0.500E+03,0.180E+03,0.,0.,0.866E+03
PL3,1,1
RP1,1,1,1000,0.515E+03,0.180E+03,0.,0.,0.857E+03
PL3,1,1
RP1,1,1,1000,0.530E+03,0.180E+03,0.,0.,0.848E+03
PL3,1,1
RP1,1,1,1000,0.545E+03,0.180E+03,0.,0.,0.839E+03
PL3,1,1
RP1,1,1,1000,0.559E+03,0.180E+03,0.,0.,0.829E+03
PL3,1,1
RP1,1,1,1000,0.574E+03,0.180E+03,0.,0.,0.819E+03
PL3,1,1
RP1,1,1,1000,0.588E+03,0.180E+03,0.,0.,0.809E+03
PL3,1,1
RP1,1,1,1000,0.602E+03,0.180E+03,0.,0.,0.799E+03
PL3,1,1
RP1,1,1,1000,0.616E+03,0.180E+03,0.,0.,0.788E+03
PL3,1,1
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APPENDIX C
NUMERICAL ELECTROMAGNETIC CODE

1. INTRODUCTION

The Numerical Electromagnetic Code (NEC) is a computer code developed at the Lawrence Livermore Laboratory, Livermore, California for the analysis of the electromagnetic response of antennas and other metal structures. It accomplishes this by numerically solving the integral equations for the currents induced on the structures by the excitation sources or incident fields. The integral equations used by the NEC program are:

- Electric field integral equation (EFIE) and
- Magnetic field integral equation (MFIE)

2. ELECTRIC FIELD INTEGRAL EQUATION (EFIE)

The NEC program uses EFIE for thin wire structures of small or vanishing conductor volume. The EFIE has also been used successfully to model surfaces with thin wire grids. The EFIE as used in NEC is:

$$\mathbf{E}(r) = -j\eta/4\pi k \int_V J(r').G(r,r')dv' \qquad \text{(eqn C.1)}$$

where:

$\mathbf{E}(r)$ = Electric field due to volume current distribution $J(r')$.

$G(r,r') = (k^2 I + \nabla\nabla)g(r,r')$

$g(r,r') = \exp(-jk|r-r'|)/|r-r'|$ (Green's function)

$k = \omega\sqrt{(\mu_0 \varepsilon_0)}$

$\eta = \sqrt{(\mu_0/\varepsilon_0)}$

The following assumptions are made in NEC for solving the EFIE for thin wires:

- Only the axial currents are considered and the transverse currents are neglected.
- The circumferential variation in the axial current is assumed negligible and therefore neglected.
- The axial current is represented by a filament on the wire axis.
- The electric field boundary conditions are enforced in the axial direction only.

With the above assumptions and considerable calculus [Ref. 4: p 3-5, vol.1], the EFIE is reduced to the following scalar form:

$$-s.\mathbf{E}^{i}(r) = -j\eta/4\pi k\int_L I(s')\,\{k^2 s.s' - \partial^2/\partial s\partial s\}\,g(r,r').ds' \qquad \text{(eqn C.2)}$$

where $\mathbf{E}^{i}(r)$ is the incident electric field, r′ is the point at s′ on the wire axis and r′ is a point at s on the wire surface.

3. MAGNETIC FIELD INTEGRAL EQUATION

The NEC program uses MFIE for voluminous structures especially one with large smooth surfaces. The MFIE fails for the thin wire analysis. For a hybrid structure consisting of both wires and surfaces the EFIE and MFIE can be combined together. The MFIE as used by NEC is given by:

$$1/2J_s(r') - 1/4\pi\int_s n(r_0)\times\{J_s(r')x\nabla' g(r_0,r')\}dA' = n(r_0)x\mathbf{H}^{i}(r_0) \qquad \text{(eqn C.3)}$$

Where J_s is the surface current distribution induced by an external field H^i and g is the free space Green's function exp(-jk|r-r′|)/|r-r′|. The magnetic field requires that only closed conducting surfaces be modeled.

4. NUMERICAL SOLUTION

The EFIE and MFIE are solved in NEC by the method of moments. For wires, a basis function is selected and the current expanded over a number of segments on the wire. The total current on the Jth segment is given by:

$$I_j(s) = A_j + B_j \mathrm{Sin}k(s-s_j) + C_j \mathrm{Cos}k(s-s_j) \qquad |s-s_j| < \nabla_j/2 \qquad \text{(eqn C.4)}$$

where ∇_j is the length of the jth segment and s_j is the value of s at the center of segment j. A_j, B_j and C_j are the three unknown constants. Two of these three unknown constants are eliminated by local conditions on the current. The third unknown constant depends on the current amplitude and is determined by the matrix equation:

$$[G][I] = [E] \qquad \text{(eqn C.5)}$$

The above matrix equation is solved by the Gauss elimination method. The matrix G is factorized into a product of an upper and a lower triangular matices. The solution for the current I is obtained by a forward and then a backward substitution.

The solution of these matrices are the most time consuming step in the analysis of a radiating structure. However symmetries of the structure can greatly reduce this computation time.

5. FEATURES

Using the EFIE and MFIE or a combination of these, the NEC code can be used to model a wide range of structures. The structure may be modeled in free space, over perfect ground or over a finite ground. The model can consist of both radiating structures, nonradiating networks and transmission lines connecting parts of the structure. The structure can be loaded with lumped load, and the load can be either resistance, inductance, capacitance or a combination of these.

The structure may be excited with either a voltage source, a current source or an incident plane wave of linear or elliptical polarization. The output options include antenna's input impedance, gain, power budget, efficiency, radiation patterns, currents, charge distribution, coupling, near field values, far field values and polarization.

6. WIRE MODELING GUIDELINES

Wire segment modeling in NEC involves both geometrical and electrical factors. A wire segment is defined by the coordinates of segment's end points and radius. Geometrically the end points of the segments should be defined such that the segments follow the path of the conductor as closely as possible. The accuracy of the results depend on both, the geometrical and electrical constraints. Following are the electrical considerations for wire segment modeling:

(a) The segment length Δ relative to the wavelength λ is a key factor:

- Δ should not be less than $10^{-3}\ \lambda$ in any case.
- Δ should be 0.05λ or less while modeling critical regions.
- Δ should be less than 0.1λ for accurate results in most of the cases.

(b) The segment radius α should be small relative to both segment length Δ and wavelength λ

- α should be less than 0.1λ
- α should be less than 0.125Δ

- α can be less than 0.5Δ, but this would need the extended thin wire kernel option by placing EK card in the data set.

(c) Connected segments must have identical coordinates for the connected ends. NEC assumes two segments ends connected, if the separation between the segments ends is less than 10^{-3} times the length of the shortest segment.

(d) Segment intersection other than at their ends does not allow current to flow from one segment to the other.

(e) Large radius changes in the wire should be avoided particularly if it consists of short segments. If the segments have large radius, then sharp bends should also be avoided.

(f) While modeling a solid structure with wire grid, a large number of segments should be used.

(g) A segment is needed at the point where a network connection, a voltage or a current source is going to be located.

(h) Base fed wire connected to ground should be vertical.

(i) The segments on either sides of the excitation source should be parallel and have the same lengths and radii.

(j) Parallel wires should be several radii apart.

(k) Before modeling a structure, the limit on the number of segments and the number of connection points should be checked in the log of dimension changes by getting the code for the particular version of NEC from the Fortran library.

7. MODELING STRUCTURES OVER GROUND

NEC offers several options for modeling antenna over ground plane. This includes modeling over a perfect ground or a ground with finite conductivity σ and permitivity ε. There are two options for modeling the structure over finite ground. One uses the reflection co-efficient approximation and the other one is based on the Sommerfeld/Norton method. The reflection co-efficient approximation is fast but less accurate as compared with Sommerfeld/Norton method. When using Sommerfeld/Norton method, NEC requires an input data file 'File FT21F001 B4', which is produced by runing a program SOMNTX. The input data file for SOMNTX run should be of type 'SDATA' containing frequency and the ground parameters ε and μ. The same frequency and the ground parameters need also be specified with the GN card in the NEC data set. The NEC program compares the complex dielectric constant $\varepsilon_c = \varepsilon_r - j\sigma/\omega\varepsilon_0$ generated by the GN card with the one produced by the SOMNTX run, if the difference is greater than 10^{-3}, it gives an error message. The input data file 'FILE FT21F001 B4' can be saved and reused for structures with the same frequency and ground parameters. While modeling structures over ground plane, care needs to be taken to specify the parameter for the GE card. The options for the use of GE card are given in Table 8.

TABLE 8
GE CARD OPTIONS IN NEC

	GE0	GE1	GE-1
No Ground	Yes	No	No
Ground	Yes	Yes	Yes
Symmetry Check	No	Yes	Yes
Buried Wires	Yes	No	Yes
Through Wires	Yes	No	Yes
Touch Wires:			
Connected	No	Yes	No
Insulated	Yes	No	Yes

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